Fire Effects in Plant Communities

on the Public Lands

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

FIRE EFFECTS IN PLANT COMMUNITIES ON THE PUBLIC LANDS

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Fire Effects

in

Sagebrush/Grass

and

Pinyon-Juniper Plant Communities

Bluegrasses

In general bluegrasses (Poa sp.) are slightly damaged by burning. Wright and Klemmedson (1965) observed no change in basal area of Sandberg bluegrass (Poa sandbergii) during any season regardless of the size of the plants. These plants were mature, dry, and contained little fuel in the crown of the plant. Tisdale (1959) reported some damage to Sandberg bluegrass in communities with 7 to 14 percent sagebrush cover. This damage was possibly caused by plants being old, pedestaled, and having an accumulation of litter in the crown. High mortality has been observed in southern Oregon when plants are pedestaled (Hammersmark, 1977). An August wildfire in northeastern California caused decreases in plant numbers (Countryman and Cornelius, 1957). Moomaw (1957) found no damage in eastern Washington. Uresk et al (1976) measured a 57 percent decrease in basal area of cusick bluegrass (P. cusickii) after an August wildfire.

On the upper Snake River plains of Idaho and Nevada, Sandberg bluegrasses showed little change in production for 3 years after burning (Harniss and Murray, 1973). This initial static perior was followed by increased yields with the burned area producing about 1.5 times more than the unburned. Thirty years after burning, yield was substantially lower on both burned and unburned areas, although the burned area was producing twice as much as the unburned. Big bluegrass (P. ampla) is not mentioned in the available literature but, due to larger clone size and greater potential accumulation of litter in the crown, it would be expected to incur slightly more damage than other bluegrasses.

Cheatgrass

Cheatgrass (Bromus tectorum) is not appreciably affected by burning although production may be reduced the first year. Abandoned fields on the Snake River plains dominated by cheatgrass were changed to primarily tumblemustard (Sisymbrium altissimum) and Russian thistle (Salsola kali) after burning for 2 to 3 years. Cheatgrass dominated these fields during the next 2 to 3 years (Piemeisel, 1938). Burning was found to reduce stands of cheatgrass in eastern Washington, presumable because of seed destruction (Robocker et al, 1965). Depending on the intensity of burn, germinable cheatgrass seed can be reduced 80 to 99 percent

(Young et al, 1976). This reduction left from 3 to 33 germinable seeds per square foot, but as few as 5 cheatgrass seeds per square foot moderately reduced establishment of crested wheatgrass. June and July burns reduced cheatgrass plant numbers to 14 and 11 per square foot compared to 41, 45, and 124 plants per square foot on August, October, and November burns, respectively near Boise, Idaho (Pehanec and Hull, 1945). These reductions are only temporary, for annuals produce abundant seed the year after a burn. Early summer burns will kill perennial grasses and allow cheatgrass to increase sharply.

Cheatgrass can rapidly occupy a burned area if only a few seeds are available (Countryman and Cornelius, 1957). Barney and Frischknecht (1974) reported that cheatgrass cover declined during the first 22 years after fire, then stabilized. This cover change varied from 12.6 percent on 3 year old burns to 0.9 percent on the oldest burns.

Idaho fescue

The majority of evidence indicates that Idaho fescue (Festuca idahoensis) is severely damaged regardless of when or where it is burned (Pehanec and Stewart, 1944; Blaisdell, 1953; Harniss and Murray, 1973). After a period of 30 years, Idaho fescue was just approaching its former abundance on the upper Snake River plains (Harniss and Murray, 1973). As a result of a summer wildfire in eastern Washington, Idaho fescue mortality was 27 percent with a reduction in basal area of 50 percent (Conrad and Poulton, 1966). In northeastern California, basal area of Idaho fescue was reduced approximately 80 percent by an August wildfire (Countryman and Cornelius, 1957).

Mid-May burns in eastern Oregon resulted in 30 percent mortality and a 48 percent reduction in basal area (Britton and Sneva, 1977). However, when the plants were dormant in the fall, no mortality resulted although there was a 34 percent reduction in basal area. Phillips (1977) observed that, in central Oregon, wildfires were more damaging to Idaho fescue on coarse soil as compared to fine textured soils. Good soil moisture was found to be beneficial to Idaho fescue survival during spring burns in Nevada (Beardall and Sylvester, 1975).

Indian ricegrass

Indian ricegrass (Oryzopsis hymenoides) is important in sagebrush-bunchgrass communities only in localized situations. As such, it has not been the subject of intensive investigations. Pechanec and Stewart (1944) mention it as being slightly damaged and slow to increase after burning.

In west-central Utah, Indian ricegrass was found to be an important species on burned areas (Barney and Frischnecht, 1974). Therefore, it probably has good survival characteristics. Spring burning in Utah did little damage to Indian ricegrass with growth initiation

about 3 weeks after burning (Jensen, 1977). Summer wildfires in Nevada cause reductions in basal area, but little mortality was noted (Wagner, 1977).

Junegrass

In eastern Oregon, junegrass (Koeleria cristata) has been found to be one of the most fire resistant perennial bunchgrasses (Britton and Sneva, 1977). Burning in mid-May reduced basal area by 32 percent with 20 percent mortality. During mid-June just after seed set, basal area was reduced 18 percent with no mortality while burning in mid-October produced only slightly more damage. This lack of appreciable damage is probably due to the relative small size of the typical junegrass clone.

Fall burning in North Dakota increased the frequency of junegrass on a sandy soil (Dix, 1960). Twelve years after burning in Idaho, junegrass yield was higher on burned areas as compared to unburned areas (Blaisdell, 1953). Countryman and Cornelius (1957) reported a slight decrease in junegrass due to a wildfire although the sample was too small for adequate interpretation.

Needlegrasses

Most needlegrasses (Stipa sp.) are damaged by burning, especially during the first year. Harniss and Murray (1973) reported a severe reduction the first year after burning needle-and-thread (Stipa comata). Season of burn rather than burning intensity or plant size was found to be the most critical factor in mortality of needle-and-thread (Wright and Klemmedson, 1965). June burns killed all of the small and 90 percent of the large plants. In July, 20 percent of the burned plants died with no mortality for August treatments. Among large plants, the average basal area reduction after June, July, and August burns was 99.6, 96, and 68 percent, respectively. The reduction in basal area for the small plants following June and July burns was 100 and 82 percent, respectively. Small plants burned in August exhibited some thinning of the crown. This damage was related to the intolerance of needle-and-thread to herbage removal and the large amounts of dead material per unit basal area (Wright, 1971). In western North Dakota, fall burning decreased needle-and-thread frequency by 11 percent on sandy soils but increased frequency by 10 percent on a clay loam soil. Observations in southern Idaho indicate that with moderate grazing treatments needle-and-thread requires 4 to 8 years after burning to fully recover.

Twelve years after burning, Blaisdell (1953) observed that needle-and-thread and Columbia needlegrass (S. columbiana) were not significantly affected by any intensity of burn, although the former produced 10 to 26 pounds more per acre on burned than on unburned range. Western needlegrass (S. occidentalis) was reduced the first year after an August

wildfire in northeastern California (Countryman and Cornelius, 1957). By the third year after burning, western needlegrass had almost doubled in basal area as compared to the unburned area.

Thurber needlgrass (S. thurburiana) is probably the least fire resistant needlegrass. Uresk et al (1976) found that an August wildfire reduced the basal area by 53 percent with a concurrent decrease in leaf length. In eastern Oregon, Thurber needlegrass was severely damaged by burning (Britton and Sneva, 1977). Plants burned in mid-May had 80 percent mortality and the basal area was reduced by 93 percent. In mid-June, mortality increased to 90 percent with a 93 percent reduction in basal area. Least damage resulted from October burns with no mortality and a 48 percent reduction in basal area. Wright and Klemmedson (1965) reported similar results for Thurber needlegrass.

Sedges

Response of sedges to burning is variable. Pechanec and Stewart (1944) list threadleaf sedge (Carex filifolia) as being severely damaged while Douglas sedge (C. douglasii) was classed as undamaged. This difference was reported to be due to the ability of Douglas sedge to initiate growth from basal buds. Twelve years after burning, Blaisdell (1953) reported sedges were producing more on light burns but less on moderate and heavy burns in one area while the opposite trend was found on another area. Threadleaf sedge was found to be producing on the average more on burned areas as compared to unburned, therefore, initial damage by burning was not permanent. Douglas sedge was reduced in number of plants as a result of wildfire in northeastern California (Countryman and Cornelius, 1957).

Squirreltail

Squirreltail (Sitanion hystrix) is one of the more fire resistant bunchgrasses, although some damage is apparent. In southern Idaho, Wright and Klemmedson (1965) observed no plant mortality as a result of burning. There was some reduction in basal area for plants burned in June, but it was most apparent (15 percent reduction) in July for both large and small plants. In August, only the large plants responded to hot burns with a 16 percent reduction in basal area. The greater overall damage in July was probably due to higher initial burn temperatures in the plant crown. Wright (1971) reported that burning generally harmed squirreltail most during May and somewhat less thereafter to increase the first year after wildfire in northeastern California but decreased by the third year (Countryman and Cornelius, 1957).

Burning squirreltail plants in a drouth year in eastern Oregon resulted in 30 percent mortality in mid-May (Britton and Sneva, 1977). No mortality was recorded for mid-June or October burns. The mid-May burns reduced basal area by 73 percent while the October burn reductions were 48 percent.

In west-central Utah, squirreltail cover was found to increase during the first 5 to 6 years after burning (Barney and Frischknecht, 1974). This increase was stable for up to 40 years. Often squirreltail plants are very small and will increase in size after a burn. The larger plants, however, would be slightly harmed (Wright, 1971; Britton and Sneva, 1977).

Wheatgrasses

Fall burning of crested wheatgrass (Agropyron desertorum) results in only small changes in the stand. Density of plants should remain unchanged (Kay, 1960), although yield may be reduced during the first growing season after burning (Lodge, 1960). After growth initiation, spring burning can reduce yield for 2 years (Lodge, 1960). Crested wheatgrass seedings are considered somewhat fireproof as many observers report that wildfires move only a few feet into a seeding.

Bluebunch wheatgrass (A. spicatum) is slightly affected by burning. Twelve years after burning, Blaisdell (1953) found a 1.7-fold increase in yield compared to unburned controls. After 30 years, yield of bluebunch wheatgrass on the same area was slightly below the controls (Harniss and Murray, 1973). Cover of bluebunch wheatgrass remained uniform in west-central Utah for 40 years after burning before the juniper overstory caused a decline (Barney and Frischknecht, 1974).

The negative effects of burning bluebunch wheatgrass are usually evident only in the first year after burning. Uresk et al (1976) measured decreases in leaf lengths and basal area, but there was an increase in yield 1 year after burning in eastern Washington. These results are similar to the 29 percent reduction in basal area and 1 percent mortality observed in the same region by Conrad and Poulton (1966). In eastern Oregon during mid-May, burning decreased the basal area by 78 percent with a 50 percent mortality. When plants were burned during the fall, there was no mortality, but a reduction in basal area of 47 percent compared to preburn measurements of the same plants (Britton and Sneva, 1977). These effects were measured during an extremely dry year which magnifies the effects of burning (Wright, 1974). Bluebunch wheatgrass will usually return to preburn production in 1 to 3 years (Blaidsell, 1953; Moomaw, 1957; Daubenmire, 1963; Conrad and Poulton, 1966; Uresk et al, 1976).

Other wheatgrasses respond somewhere between crested wheatgrass and bluebunch wheatgrass with the exception of the rhizomatous wheatgrasses. Thickspike wheatgrass (A. dasystachyum) exhibits virtually no change 1 year after burning, and after 12 years was producing about twice as much as unburned controls (Blaisdell, 1953). It appeared that the more intense the burn the greater the response. In northeastern California, a mixed wheatgrass stand was burned in the fall of the third growing season (Kay, 1960). The following summer, a 25 percent increase in stocking was measured and was primarily due to rhizomes of

intermediate wheatgrass (A. intermedium) and pubescent wheatgrass (A. trichophorum). Tall wheatgrass (A. elongatum) remained unchanged. In North Dakota, western wheatgrass (A. smithii) was unchanged in frequency regardless of site or soil (Dix, 1960).

Forbs

Forbs generally respond better to burning than do grasses. Where plant communities have large proportions of forbs in the herbaceous component, burning may provide the best manipulation technique. Fall burning does not harm most forbs because they are often dry and disintegrated by this time. Pechanec and Stewart (1944) classified forbs according to their susceptibility to fire.

Due to lack of research evidence on individual forb species, no attempt will be made to review each species mentioned in the literature. Instead each article mentioning forbs will be abstracted.

Probably the best research treatment of forbs is from the prescribed burns conducted in Clark and Fremont counties on the upper Snake River plains of Idaho. This work is presented in a series of three articles by Pechanec et al (1954); Blaisdell (1953); and Harniss and Murray (1973). Pechanec et al (1954) observed that the rapidity of increase by the lightly damaged or undamaged species depended largely on whether the plant spreads by rootstocks. Those that do not, even though undamaged, increase slowly after burning. These include some of the more palatable species such as arrowleaf balsamroot (Balsamorhiza sagittata) and tailcup lupine (Lupinus caudatus). Despite a ready recovery from burning, any increase in number of plants must await seed production.

Plant species spreading by rootstocks or root shoots are least harmed and spread most rapidly after burning. These species include western yarrow (Achillea lanulosa), purpledaisy fleabane (Erigeron corymbosus), longleaf phlox (Phlox longifolia), flaxleaf plainsmustard (Sisymbrium linifolium), and common commandra (Commandra umbellata). Such species as western yarrow, longleaf phlox, and purpledaisy fleabane doubled in production within 3 to 4 years.

Approximately 12 years after the burns in Clark and Fremont counties, Blaisdell (1953) reevaluated the vegetation response. He found that total forb production was considerably higher on all burn intensities as compared to unburned areas in Fremont county. For unburned, light burn, moderate burn, and heavy burn areas, forb production in pounds per acre was 127, 191, 237, and 170 respectively. Of the species mainly responsible for the higher yield of forbs on burned areas, western yarrow, aster (Aster sp.), fleabane, and goldenrods (Solidago sp.) are rhizomatous perennials. Littleleaf pussytoes (Antennaria microphylla), a woody stemmed form of low forage value, and sticky geranium (Geranium viscosissimum), a perennial rated fair

forage, also contributed to the higher yield, especially on light and moderate burns. On the other hand, yield of knotweed (Polygonum douglasii), an undesirable annual, was greatest on the heavy burn. The lower yield of plymeweed (Cordylanthus ramosus) on the burned areas as compared to unburned did approach statistical significance.

The 1934 inventories showed a marked increase in total production of forbs on burned areas in relation to that on the unburned. This trend continued through the third year, especially on burns of light and moderate intensity. Although much of these early increases had disappeared by 1948, differences were still significant for light and moderate burns.

Rhizomatous species on all burn intensities showed relative increases the first year after burning, but subsequent trends were variable. On the other hand, woody forbs (pussytoes and eriogonum (Eriogonum caespitosum and E. heracleoides)) decreased markedly, roughly proportionate to burn intensity, and then increased. Annuals, primarily gayophytum (Gayophytum diffusum), knotweed, plumeweed, and goosefoot (Chenopodium sp.), made enormous relative increases in 1934, roughly in proportion to burn intensity. Portions of these relative increases persisted through 1936, but had disappeared by 1948 on all but the heavy burn. The persistence of annuals on the heavy burn was shown by actual yield of knotweed, 26 pounds on the heavy burn as compared to 7 on the unburned. Other perennial forbs generally showed an initial but temporary increase after burning.

After 12 years, only the heavy burn in Clark county supported a significantly higher yield of forbs compared to the unburned area. It appeared that fleabane and phlox (both rhizomatous species) on burns of all intensities and lupines on the heavy burn were producing more than on the unburned. Apparently the effect of burning on the other forbs was negligible after 12 years.

In contrast with Fremont county, inventories of Clark county plots the year after burning showed a decrease in total forb production on burned areas in relation to the unburned. By the third year considerable increases in relative yield were evident, but most of these early effects disappeared during the next 9 years. As in Fremont county, rhizomatous forbs generally increased the first year, but woody species, eriogonum and pussytoes decreased markedly on all burns. Rhizomatous species continued to increase through the third year then decreased. After the initial relative decreases, woody species increased throughout the study period and regained much of their original losses. With the exception of plumeweed, annuals were present only in very small amounts. Other perennial forbs increased the first year on burns of all intensities, but trends in following years were not well defined.

By 1966, Harniss and Murray (1973) found little difference in forb production on burned and unburned plots. Although individual species were not mentioned, perennial forbs accounted for the bulk of the production.

Abandoned fields on the Snake River plains dominated by cheatgrass were burned during the early 1930's (Piemeisel, 1938). The first year after burning, the major portion of the vegetation was tumblemustard and Russian thistle with some flixweed tansymustard (Descurainia sophia). It took 2 to 3 years for the fields to again be dominated by cheatgrass. Near Dubois, Idaho, Mueggler and Blaisdell (1958) reported an increase in forb production after burning. Those species most benefitted included timber poisonvetch (Astragalus convallarius), purpledaisy fleabane, and lupine. Forbs that were injured include littleleaf pussytoes and matroot penstemon (Penstemon radicosus).

In western North Dakota, Dix (1960) found that wild lettuce (Lactuca pulchella) decreased about 20 percent with the most dramatic decrease (63 percent) on loamy fine sand. Red globemallow (Sphaeralcea coccinea) increased when present in the vegetation.

Robocker et al (1965) found on a sandy soil in eastern Washington that burning decreased most forbs. Burning appeared to have reduced stands of tumblemustard, tansymustard (Descurainia pinnata), and whitlow-wart (Draba verna).

In west-central Utah, Barney and Frischknecht (1974) sampled burns ranging in age from 3 to over 100 years. The most abundant forbs during the first stages of succession were pale alyssum (Alyssum alyssoides), flixweed tansymustard, sunflower (Helianthus annuus), coyote tobacco (Nicotiana attenuata), and Russian thistle. Since these forbs were abundant on recent burns, it can be assumed that they were not seriously damaged by burning.

Yarrow was found to decrease the first 2 years after burning in northeastern California (Countryman and Cornelius, 1957). However, by the fifth year there was a 7.5-fold increase in crown area.

In eastern Oregon, tailcup lupine changed slightly in cover from an average of 15 percent to over 16 percent 1 year after fall burning (Britton and Sneva, 1977). The burns were in a dry year followed by a drier year. Hammersmark (1977) observed in southern Oregon that astragalus, arrowleaf balsamroot, tapertip hawksbeard (Crepis acuminata), tailcup lupine, globemallow, and foothill deathcamas (Zigadenus paniculatus) were not damaged by wildfire. In Nevada, Wagner (1977) measured a three-fold increase in frequency of longleaf phlox with no reduction in wild onion, astragalus, tapertip hawksbeard, lupines, globemallow, and foothill deathcamas as a result of wildfire.

Shrubs

Bitterbrush

The specific effects of fire on bitterbrush depends on the species and location (Nord, 1965). For example, abundant resprouting of antelope bitterbrush (Purshia tridentata) occurs in eastern Idaho (Blaisdell, 1953; Blaisdell and Mueggler, 1956), limited resprouting occurs in central and northern Utah (Blaisdell and Mueggler, 1956) and very little resprouting occurs in Oregon and California (Nord, 1965). Billings (1952) reports that fire eradicates bitterbrush in the western Great Basin because it rarely root-sprouts in that region, and seeds of bitterbrush do not disseminate from their source. Klebenow et al (1976) report that bitterbrush resprouts in Nevada generally died the year following burning. However, good production from seed resulted from the burn. The natural frequency of fire in areas that contain antelope bitterbrush is probably not more than 41 to 50 years, if that often.

Generally speaking, antelope bitterbrush is a weak sprouter and living plants are severely damaged by fire (Blaisdell; 1953, Pechanec et al, 1954; Countryman and Cornelius, 1957; Nord, 1965). For antelope bitterbrush to resprout regularly in areas such as southeastern Idaho, the soil must be wet at the time of the burn or shortly after the burn (Blaisdell, 1953; Blaisdell and Mueggler, 1956; Nord, 1965). Otherwise, antelope bitterbrush seldom resprouts. If antelope bitterbrush plants do resprout, they will regain their original growth in 9 to 10 years (Blaisdell, 1953). For a burn in Idaho that was followed by some dry years, antelope bitterbrush was only producing 50 to 60 percent as much as the control 12 years after the burn (Blaisdell, 1953).

Ecotypic variation would normally be expected within a wide-ranging species like bitterbrush. Alderfer (1977) reports three ecotypes in northern California and Oregon, a high elevation decumbent form, and two columnar forms. Monsen (1977) has indicated three types occurring in Idaho, a low elevation decumbent form and two columnar forms, with one on granitic soils and the other on calcareous soils. In Utah, Plummer suggests that the decumbent and columnar forms represent at least two types.

The decumbent ecotype generally resprouts after fire or top removal. It is an aggressive pioneer species capable of revegetating highly disturbed areas after planting (Monsen and Christenson, 1975). The columnar form on granitic soils in Idaho will also generally resprout after fire or top removal, but resprouting seems to be dependent on fire intensity and soil moisture. The other ecotypes apparently are more severely damaged by fire.

The decumbent form is easily planted from seed and is successfully used for rangeland and logging road rehabilitation, particularly on well drained, coarse textured soils (Monsen and Christenson, 1975). Since seeds must be cold treated and scarified (Young and Evans, 1976), the best time to burn for seed production is the fall (Monsen and Christenson, 1975). Abundant natural regeneration from seed caches following fall prescribed burning has been reported by Klebenow et al (1976). Seedlings from the low growing forms of antelope bitterbrush appear more competitive than do the upright forms (Monsen and Christenson, 1975), and germination is high (Holmgren, 1954). However, seedlings cannot compete with annual grasses during the first growing season (Holmgren, 1956).

Desert bitterbrush (Purshia glanulosa) usually resprouts after fire (Nord, 1965). This species is closely related to antelope bitterbrush and the two interbreed (Monsen and Christenson, 1975) when their populations overlap. The amount of genetic variation induced by interbreeding significantly affects both palatability and resprouting in antelope bitterbrush.

Tentative conclusions deduced from the data presented on antelope bitterbrush follows: (1) High intensity wildfires during mid-summer do the most damage to bitterbrush when the burning is followed by summer drouth; under these conditions, most of the bitterbrush is killed. Cool spring burns in the decumbent ecotype(s) of bitterbrush result in low mortality and high resprouting; however, few seedlings establish in the burned area. Fall prescribed burns result in higher mortality than spring burns, but lower mortality than summer burns. If fall prescribed burns are conducted with favorable soil moisture conditions at the time of the burn or just after the burn, resprouting and layering occur in the decumbent ecotype. Reproduction from seed is highest following a fall burn. (2) Fire harms the columnar ecotypes more than it does the decumbent ecotypes. Cool fall fires are more important for the survival of antelope bitterbrush in the upright growth forms than in the low growth life forms. (3) Fire harms bitterbrush more on fine textured and calcareous soils than on coarse textured and well drained soils. Specific habitat and soils data are not available.

Cliffrose

Two varieties of cliffrose are recognized (Cowania mexicana var. mexicana and var. stansburiana). Apparently, Stansbury's cliffrose is a stronger sprouter and an aggressive pioneer species, whereas the mexicana cliffrose is a weak sprouter and not so aggressive. Research on Cowania mexicana shows that it is generally killed by fire (Pechanec et al, 1954; Vallentine, 1971; Klebenow et al, 1976). Like desert bitterbrush, cliffrose interbreeds with antelope bitterbrush (Nord, 1965; Sanderson, 1969).

Sagebrush

Big sagebrush (Artemisia tridentata) is easily killed by fire (Blaisdell, 1953; Pechanec et al, 1954; Ralphs et al, 1975). Blaisdell (1953) reports that big sagebrush does not resprout in southeastern Idaho, and repeated burning can almost completely eliminate sagebrush from a site (Pickford, 1932). However, without repeated fires, sagebrush will reinvade the burned area via seeding. Sagebrush begins to reoccupy the area during the first year after the burn. Working at Dubois, Idaho, Blaisdell (1953) found that sagebrush in burned areas (12 years after the burn) was 10 percent of that in unburned areas, but had reached unburned levels in 30 years (Harniss and Murray, 1973). Some areas recover more quickly if seed and moisture are available after burning (Pechanec et al, 1954; Johnson and Payne, 1968).

Mountain sagebrush (A. tridentata subsp. vaseyana) recovers more quickly than other subspecies of big sagebrush, perhaps because it occupies more mesic sites and growing conditions are more favorable for seed production and reestablishment (Hironaka, 1977). Winward and Tisdale (1977) indicated that it shows a stronger tendency to increase in plant density and foliage cover in stands where the herbaceous vegetation is disturbed than basin big sagebrush (A. tridentata subsp. tridentata) or Wyoming big sagebrush (A. tridentata subsp. wyomingensis). Basin big sagebrush normally occupies lowland plains and valleys on basic soils whereas Wyoming big sagebrush occupies drier valley and foothill sites (Plummer, 1977). Though seed production is variable, depending on soil moisture conditions, germination rates of all three subspecies of big sagebrush are high enough in all years to exclude seed germination as a limiting factor to reinvasion (Harniss and McDonough, 1976).

High intensity wildfires leave few unburned plants and consume most seeds, which accounts for the variable density of reinvading big sagebrush. Maximum spread of progeny from parent plants of big sagebrush is 42 feet (Frischknecht, 1962), so wind is evidently not a big factor in moving seed from adjacent unburned areas into burned areas. Normally, seeds of big sagebrush do not remain viable in the soil or litter for more than 3 to 5 years (Monsen, 1977).

Other important closely related species are the lower growing black sagebrush (A. nova), low sagebrush (A. arbuscula), silver sage (A. cana), and three-tip sagebrush (A. tripartita). Fires rarely occur in the black and low sagebrush types. These shrubs grow in areas of shallow and droughty soils where production of herbaceous plants is often inadequate to support a fire. Black and low sagebrush can reproduce seed after a fire, but do not resprout. Three-tip sagebrush is a weak sprouter and silver sagebrush is a vigorous sprouter.

Rabbitbrush

Rabbitbrush (*Chrysothamnus* sp.) a common genera in the sagebrush-grass zone, is usually enhanced by fire (Cottam and Stewart, 1940; Blaisdell 1953; Countryman and Cornelius, 1957; Chadwick and Dalke, 1965; Young and Evans, 1974). An exception to this general response are two observations by Robertson and Cords (1957) for rubber rabbitbrush (*Chrysothamnus nauseosus*). This species showed no recovery 2 years after a burn on September 3, 1942 near Mono Lake, California and after a burn on November 7, 1943 near McGill, Nevada. However, a burn on the latter area was repeated the following year on the same date and 95 percent of the plants resprouted. Generally, this is what we expect to happen, but obviously there are conditions under which rubber rabbitbrush can be killed. Evidently, the intensity of the fire is important since most of the sprouting after fire is epicormic (stem sprouting), not basal or root sprouting (Monsen, 1977).

Chrysothamnus puberulus, *C. bloomeri*, *C. lanceolatus*, and *C. viscidiflorus* all resprout vigorously and reseed well on disturbed areas (Plummer, 1977). Seeds will carry long distances and growth of seedlings is rapid.

For living plants that resprout, production is reduced for 1 to 3 years after burning, then it increases dramatically (Blaisdell, 1953). On the U.S. Sheep Station near Dubois, Idaho, burning reduced production 59 percent the first year after burning (Blaisdell, 1953). Three years after burning, production doubled and was tripled at the end of 12 years. Similarly, Chadwick and Dalke (1965) found that the cover of *C. viscidiflorus* had increased four to nine times on 8 to 18-year-old burns on sandy soils in northeastern Idaho. Production of *C. bloomeri* doubled 5 years after a burn in northern California (Countryman and Cornelius, 1957). In western Nevada, Young and Evans (1974) found that green rabbitbrush (*C. viscidiflorus* var. *viscidiflorus*) continued to dominate burns and reestablish itself periodically for 15 years. Communities 40 to 50 years old were dominated by big sagebrush and contained reduced populations of green rabbitbrush.

Broom Snakeweed

Broom snakeweed (*Gutierrezia sarothrae*) is a weak sprouting perennial that is severely damaged by fire (Pechanec et al, 1954; Wright, 1972). It may be completely removed from an area (Stanton, 1973). New plants tend to invade open areas rapidly, and the highest frequencies of broom snakeweed are found on 22-year-old burns (Barney and Frischknecht, 1974). Populations decline gradually for 50 years. On 100-year-old burns, populations are reduced to less than 10 percent (Barney and Frischknecht, 1974).

Horsebrush

Horsebrush (Tetradymia canescens) is a vigorous postfire sprouter that also reproduces abundantly from seed. Species of horsebrush cause liver damage to sheep with symptoms of photosensitization developing into severe poisoning (Kingsbury, 1964). Fire may reduce horsebrush by 50 percent the first year after a burn, but the species doubles at the end of 3 years after a burn (Blaisdell, 1953). Twelve years after the burn many plants become decadent and begin to die out (Harniss and Murray, 1973). If fire or chemicals are used to treat decadent growth, horsebrush will become overwhelmingly dominant.

In addition to spineless horsebrush (Tetradymia canescens), littleleaf horsebrush (T. glabrata) and catclaw or spiney horsebrush (T. spinosa) resprout after fire. However, littleleaf and catclaw horsebrush normally grow in drier sites in which there is not enough fuel to carry a fire (Hironaka, 1977). Hence, only spineless horsebrush is a potential problem following prescribed burning.

Gambel's Oak

In Colorado, fire stimulates suckering of Gambel's oak with a resultant thickening and merging of stands into continuous thickets (Brown, 1958). In Utah, McKell (1950) found that Gambel's oak grew rapidly the first two growing seasons (50 percent recovery) after burning, but it had only recovered 75 percent of its original cover in 18 years after the burn (Wright, 1972). The number of shoots increased after the fire and then they declined until they were equal on both burned and unburned areas 18 years after the burn (Wright, 1972). Oak tends to thin out and retreat when protected from fire (Brown, 1958).

Snowberry

After fire, common snowberry (Symphoricarpos albus) will resprout vigorously from both rhizomes and basal buds. Creeping snowberry (S. mollis) is found in moister habitats. It is a weak sprouter after fire because its rhizomes, which may develop in deep humus, are sometimes consumed in an intense fire (Stickney, 1977). Mountain snowberry (S. oreophilus) is found in drier habitats extending into sagebrush grass. It is a weak sprouter after fire. Pechanec et al (1954) and Blaisdell (1953) found that it decreased initially after burning although no further change was observed 12 years after burning.

Snowberry is capable of producing fire brand material. When snowberry is located near fire control lines, it should be red flagged as spot-fire potential.

Mountain-mahogany

True mountain-mahogany (Cercocarpus montanus) is a vigorous sprouter after being burned (Erdman, 1970; Vallentine, 1971). It is also highly palatable and of major importance in the western United States (Medin, 1960).

Curlleaf mountain-mahogany (C. ledifolius) is a weak sprouter after being burned, but many of the resprouts die during the following two or three seasons (Monsen, 1977). Curlleaf is a slow growing species, particularly as a seedling, but it can grow into a small tree (Dealy, 1975). The ability to resprout after pruning decreases as the age and size of the plant increases (Ferguson and Basile, 1966: Ferguson, 1968). Few tree-like curlleaf mountain-mahogany plants resprout after fire (Monsen, 1977).

Rose

Several members of the rose family respond similarly to fire. Throughout their ranges, serviceberry (Amelanchier alnifolia), ocean-spray (Holodiscus discolor), ninebark (Physocarpus malvaceous), bittercherry (Prunus emarginata), little-wild rose (Rosa gymnocarpa), woods rose (Rosa woodsii), and shiny-leaf spiraea (Spiraea betulifolia), resprout from a root crown. They resprout in habitats of subalpine fir (Lyon, 1976), grand fir (Asherin, 1972), cedar-hemlock (Mueggler, 1965; Leege, 1968), Douglas fir (Lyon, 1971), ponderosa pine (Daubenmire, 1968), oak-brush (McKell, 1950), and sagebrush (Neuenschwander, 1977). Vegetative reproduction following burning is the primary method of propagation. Reproduction from seed is rarely observed after a burn. When seedlings are observed in a burn, their rate of growth is slow compared to that of other species (Stickney, 1977).

Serviceberry

Serviceberry may be the most palatable browse species and the most fire sensitive within the rose family. At least two growth forms are recognized (Lonner, 1972) with several varieties. The driest variety, western serviceberry (Amelanchier alnifolia var. utahensis), is damaged by fire but it resprouts (Stanton, 1973; Wright, 1972). The more mesic variety, common serviceberry (A. alnifolia var. alnifolia), also resprouts and is not severely harmed. Based on observations in southern Idaho and in Utah, no mortality following wildfires has been recorded for Utah serviceberry (Monsen, 1977). Apparently western serviceberry, which is a long-lived species (Hemmer, 1971), can remain suppressed in a closed stand of conifers or juniper for a long period of time. Canopy removal from the resident trees will stimulate resprouting (Asherin, 1972; Lyon, 1971).

Ceanothus

Most seeds of Ceanothus can withstand high external temperatures and maintain germination capabilities (Biswell, 1974). Snowbrush (C. velutinus) and redstem ceanothus (C. sanguineus) seeds require heat scarification before they will germinate (Lyon, 1976). In addition, they resprout after fire. Sprouting may be considered an adaptation to recurring fires (Biswell 1974) because of the rapid growth and recovery after fire. Thus, Ceanothus is well adapted to fire for two reasons: (1) Many of the shrubs resprout after fire; (2) seeds which are reproduced at an early age may lie dormant and viable in the duff and soil for extremely long periods of time, and are highly resistant to fire. Seedlings are usually abundant after fire.

In one study by Leege (1968) in which he compared spring burns to fall burns to rejuvenate redstem ceanothus, spring burns were found to stimulate more resprouts than fall burns, but few seedlings of redstem ceanothus were alive by the end of the second growing season after the burn. However, many seedlings of redstem ceanothus survived the fall burn. Leege's study findings, if applicable to other species of Ceanothus, may imply that spring burning could potentially harm the species that reproduce primarily by seed. Late summer or fall burning, however, would increase the number of young plants. Frequent fires could possibly remove Ceanothus species reproducing by seed from an area, or at least, favor plants that resprout.

Conclusion. The effect of fire on shrubs is variable, enhancing some species and damaging others. The state of the art on the effects of fire on shrubs of the drier forest and sagebrush-grass zones of the Intermountain Region, as presented, indicates that most of the data collected are superficial and, in many cases, inadequate. However, baseline data on response to fire is available for key species even though specific data is lacking.

Research should be undertaken on key shrubs to determine specific effects of fire. Survival and reproductive capabilities of the key shrub species, subspecies, and ecotypes need to be correlated with habitat and/or soil type, soil moisture, season of burning, and fire intensity. In addition, proper grazing managment for key species following the fire has not been determined.

In light of research needs, resource managers should document burns as to soil moisture (wet or dry), season of burn (date), fire intensity (hot vs. cold), and habitat type.

Pinyon and Juniper

The effect of fire on living pinyon and nonsprouting juniper trees depends largely upon the height of trees, herbaceous fuel, weather conditions, and season. In open pinyon-juniper stands with an understory of 700 to 1,000 lb/acre of fine fuel, Jameson (1962) and Dwyer and Pieper (1967) found that pinyon and juniper were easily killed by spring fires if less than 4 feet tall when air temperature was 70 to 74° F, relative humidity 20 to 40 percent, and wind speed is 10 to 20 mph. Lower air temperatures in January (49 to 54° F), relative humidity 44 percent, and wind of 6 to 8 mph caused a very spotty burn in which crown kill varied from 30 to 70 percent of trees 2 to 4 feet tall, but 70 percent of the trees died (Jameson, 1962). A wildfire in June with an air temperature of 97° F, wind 10 to 15 mph, and relative humidity 17 to 25 percent assured a 100 percent kill of all trees less than 4 feet tall, but was no more effective on taller trees than when air temperatures were 70 to 74° F (Jameson, 1962).

Trees greater than 4 feet tall in open pinyon-juniper stands are difficult to kill unless you have excess accumulations of fine fuel beneath the trees. On the wildfire studied by Dwyer and Pieper (1967), only 24 percent of the pinyon and 13.5 percent of the juniper which exceeded 4 feet died. Jameson (1962) found that most juniper over 4 feet tall only had a 30 to 40 percent crown kill, unless tumbleweeds had accumulated at the base of the trees. Then 60 to 90 percent of the crowns were killed, particularly for trees 8 to 10 feet tall. East of the pinyon-juniper zone in Texas, juniper trees up to 12 feet tall were easily killed when fine fuel was 2,000 lb/acre (Wink and Wright, 1973).

Trees in closed stands (no grass or shrubs in the understory) of pinyon-juniper are difficult to kill because fires won't carry easily (Arnold et al, 1964; Blackburn and Bruner, 1975). Dense stands (495 to 988 trees/acre) in 14 to 18-inch rainfall areas with a mixture of pinyon and juniper can be burned on hot days, but pure stands of juniper are almost impossible to burn (Blackburn and Bruner, 1975). A number of people of the Great Basin area speculate that it would require winds over 35 mph to burn pure stands of juniper. Thus, many attempts to burn such stands have failed (Arnold et al, 1964; Aro, 1971). As the proportion of pinyon to juniper increases and the density increases, the stands are easier to burn (Truesdell, 1969; Blackburn and Bruner, 1975). Such areas are usually burned by clearing an area 20 to 125 feet wide and pushing a windrow against the green trees on the windward side and letting the material cure for 60 to 90 days. Then in June or July, burns are conducted when temperatures vary from 80 to 95° F, relative humidity is 4 to 8 percent, and winds exceed 8 mph (Truesdell, 1969; Blackburn and Bruner, 1975). These burns have been conducted on mesas or next to the Grand Canyon where firebrands are not a problem.

A mixture of sagebrush and pinyon-juniper is common throughout the Great Basin, and it is feasible to burn and kill large pinyon and juniper trees in these communities (Bruner and Klebenow, 1978). To get a fire to carry, Bruner and Klebenow (1978) have proposed the "White Pine County Formula" where,

Index = Maximum Wind (mph) + Shrub and Tree Cover (%) + Air Temperature (° F).

If the index is 110 or higher, a fire will carry and will kill the large pinyon and juniper trees. If the index is above 130, it is too dangerous to burn. Most of the work by Bruner and Klebenow has been done in pinyon-juniper stands with 45 to 60 percent of shrub and tree cover and burned when air temperature was 60 to 75° F, relative humidity was below 25 percent, and maximum wind speed was 5 to 25 mph.

Alligator juniper and redberry juniper are the only sprouting species. Smith et al (1975) found that if the tops of redberry juniper trees were removed before they reached 12 years of age, 99 percent mortality could be expected. Older trees were not studied. This data implies that if subjected to fire every 10 years or so, sprouting species of juniper may have a difficult time invading grasslands. Schroeder (1956) found that about 40 percent of alligator juniper trees less that 15 feet tall could be killed by burning individual plants (quoted by Blackburn and Bruner, 1975).

Table 1. Relative Response of Cold Desert Grass and Grass-like Species to Burning.

Severely damaged	Slightly damaged	Undamaged
Idaho fescue	Bluebunch wheatgrass	Cheatgrass
Needle-and-thread	Big bluegrass	Crested wheatgrass
Threadleaf sedge	Columbia needlegrass	Douglas sedge
Thurber needlegrass	Cusick bluegrass	Intermediate wheatgrass
	Indian ricegrass	Plains reedgrass
	Nevada bluegrass	Prairie junegrass
	Squirreltail	Pubescent wheatgrass
	Western needlegrass	Riparian wheatgrass
		Sandberg bluegrass
		Tall wheatgrass
		Thickspike wheatgrass
		Western wheatgrass

Table 2. Relative Response of Cold Desert Forbs to Fall Burning.

Severely damaged	Slightly damaged	Undamaged
Hairy fleabane	Astragalus	Arrowleaf balsamroot
Hoary phlox	Matroot	Common camandra
Littleleaf pussytoes	Munro globemallow	Common sunflower
Low pussytoes	Northwestern paint-brush	Coyote tobacco
Mat eriogonum	Pinnate tansymustard	Douglas knotweed
Uinta sandwort	Plumeweed	Flaxleaf plainmustard
Wyeth eriogonum	Red globemallow	Flixweed tansymustard
	Sticky geranium	Foothill deathcamas
	Tailcup lupine	Gayophytum
	Tapertip hawksbeard	Goldenrod
	Tongueleaf violet	Goosefoot
	Tumblemustard	Lambstongue groundsel
	Wavyleaf thistle	Longleaf phlox
	Whitlow-wart	Orange arnica
	Wild lettuce	Pale alyssum
		Purpledaisy fleabane
		Russian thistle
		Velvet lupine
		Western yarrow
		Wild onion

Table 3. Summary of the Effect of Fire on Major Shrub Species in the Drier Forest and Sagebrush Grass Zones of the Intermountain Region.

Species	Sprouting Ability	Response to Fire	Recovery Time	Remarks
Antelope bitterbrush	Weak sprouter	Severely damaged by summer and fall burns	30 to 40 years	Effect determined by growth form; decumbent form sprouts vigorously, columner form is a weak sprouter. If plants sprout, they will recover in 9 to 10 years. Spring burns enhance sprouting but fall burns are best for reproduction from seed. Burn when soil is wet.
Desert bitterbrush	Sprouter	Unharmed		
Cliffrose	Weak to non-sprouter	Usually killed by fire		
Big sagebrush	Non-sprouter	Severely harmed	30 years	Good seed crop before burning hastens recovery. Effective control requires burning before seed-set and periodic burns. May use black and low sage as fuel breaks. Subspecies of big-sagebrush appear to be important relative to response to burning.
Black sagebrush	Non-sprouter	Rarely burned		
Low sagebrush	Non-sprouter	Rarely burned		
Silver sagebrush	Sprouter	Slightly harmed		
Three-tip sagebrush	Week Sprouter	Harmed	30 years	
Rubber rabbitbrush	Vigorous sprouter	Enhanced	20-25 years	May be killed if burned after heavy grazing or burned in early summer.
Green rabbitbrush	Vigorous sprouter	Enhanced	20-25 years	
Broom snakeweed	Weak sprouter	Severely harmed	20-25 years	Rapid recovery.
Horsebrush	Vigorous sprouter	Enhanced	30-35 years	Toxic, increases 5-fold within 12 years.
Gambel's oak	Vigorous sprouter	Enhanced	30-40 years	

Table 3. (Continued)

Species	Sprouting Ability	Response to Fire	Recovery Time	Remarks
Common snowberry	Vigorous sprouter	Unharmed	10 years	Enhanced by cool fires but harmed by hot fires.
Mountain snowberry	Sprouter	Slightly harmed	15 years	
Mountain mahogany	Sprouter	Slightly harmed		More information is needed.
Western mahogany	Sprouter	Slightly harmed		
Curlleaf mahogany	Sprouter	Moderately harmed		
Serviceberry	Sprouter	Slightly harmed	30-50 years	Highly adapted to fire; soil moist at the time of the burn is important. Usually poor reproduction from seed.
Ocean-spray	Sprouter	Enhanced	20-30 years	
Ninebark	Sprouter	Enhanced	20-30 years	
Bittercherry	Sprouter	Unharmed	30-40 years	
Rose	Sprouter	Enhanced	15-30 years	
Spirea	Sprouter	Unharmed	20-30 years	
Ceanothus				
Non-sprouting group	Non-sprouters	Harmed by spring fires		
Sprouting group	Vigorous sprouters	Unharmed to enhanced		Seedlings are enhanced with fall burns.

PRESCRIPTION GUIDES

Sagebrush-Grass Communities

Big Sagebrush and Grass

Sagebrush is diffucult to burn unless there is at least 600 to 700 lbs/acre of herbaceous fuel (Beardall and Sylvester, 1976). Moreover, burning should not be considered as a management tool unless the cover of big sagebrush exceeds 30 percent (Pechanec et al, 1954). After the decision to burn has been made, try to avoid burning immediately after heavy seed crops for the sagebrush can reoccupy the burned area rapidly with good moisture (Pechanec et al, 1954; Johnson and Payne, 1968). Early spring or later summer (August) burns may be the most preferable (Blackburn and Bruner, 1975; Beardall and Sylvester, 1976). Good soil moisture down to 12 to 18 inches should be present before burning.

Various procedures have been used to conduct prescribed fire in sagebrush/grass communities. Pechanec et al (1954) plowed a single 8-foot fireline completely around an area in southeastern Idaho. Then immediately adjacent to the fireline on the downwind side, they plowed another line with the berm pushed to the center of the plowed area. This berm acted as a buffer for firebrands rolling along the ground. Then Pechanec et al (1954) plowed a final line 100 to 200 feet inside the burn, parallel to the double fireline. This uncleared strip (usually the north and east sides of a 400 to 600-acre block) was burned with backfires or strip headfires in the forenoon when the wind was 5 to 8 mph and the humidity was about 40 percent in late August. After the uncleared strip had been burned, the remaining area was burned with a headfire, starting about 2:30 to 3:00 p.m., presumably when air temperature was above 75° F, relative humidity was 15 to 20 percent, and wind was 8 to 15 mph (Ralphs et al, 1976).

A burning technique similar to that of Pechanec et al (1954) was used at the Benmore Experimental Range in central Utah (Blackburn and Bruner, 1975). Their firelines varied from 20 to 150 feet, with the narrow lines being on the upwind side (Davis, 1976). Davis (1976) states that, based on theoretical values and experience, flash fuels can be expected to ignite 50 to 90 feet ahead of an advancing front in sagebrush-grass. This implies that a 100-foot fireline on the downwind side of a fire should be adequate.

Some people have used a wet line in lieu of a plowed line in cheatgrass (Bromus tectorum). This is done by wetting a line and letting the fire back away from it. This can be done easily in cheatgrass on smooth terrain. In rough topography, however, this technique would not be feasible.

Recommendation: Based on the above data and research by Ralphs et al (1976), we recommend dozing a 10 to 12-foot fireline around the area to be burned (preferably about 450 acres according to Davis, 1976). Then strip headfire a 150-foot strip on the leeward sides during the morning hours when wind is 5 to 8 mph and humidity is about 40 percent. As the fire backs up in heavy fuel beyond the 150 foot strip, use a pumper to put the fire out. About 2:00 p.m., headfire the remaining area when the temperature is above 75° F, relative humidity is 15 to 20 percent, and wind is 8 to 15 mph (Ralphs et al 1976).

Big Sagebrush and Low Sagebrush

Where dense stands of big sagebrush are mixed with low sagebrush (*Artemisia arbuscula*), no firelines need to be prepared because fires won't carry in low sagebrush even during a hot day with winds up to 25 mph (Beardall and Sylvester, 1976). Thus, the burns can be conducted on warm days with gusty winds whenever it is convenient.

Recommendation: Beardall and Sylvester (1976) suggest burning in early spring when relative humidity is below 60 percent, wind speed is above 8 mph, and only if you have more than 600 to 700 lb/acre of fine fuel. Late summer burning has not been tested in this area because it might do considerable harm to sensitive grasses such as Idaho fescue (*Festuca idahoensis*).

Big Sagebrush with Snowbanks as Natural Barriers

Use the same procedure as for mixtures of big and low sagebrush.

Pinyon-Juniper Communities

Open Stands of Pinyon-Juniper with Grass Understory

In this vegetation type, fire is only effective in killing pinyon and juniper trees that are less than 4 feet tall (Jameson, 1962; Arnold et al, 1964; Dwyer and Pieper, 1967). Moreover, as near as we can tell, at least 600 to 700 lb/acre of fine fuel is needed to carry the fire. Trees greater than 4 feet tall will not be killed unless they have accumulations of tumbleweeds at the base (Jameson, 1962).

Recommendation: Doze a fireline 10 to 12 feet wide around the area to be burned. About 450 acres would be a good-sized unit (Davis, 1976). Strip headfire a 100-foot strip in the leeward sides of the planned burn during evening or morning hours in the spring. Where fire continues to back up beyond the 100-foot strip, put it out with a pumper. Then headfire the remainder of the area when the temperature is 70 to 74° F, relative humidity is 20 to 40 percent, and wind speed is 10 to 20 mph (Jameson, 1962; Dwyer and Pieper, 1967).

Closed Stands (No Grass or Shrub Understory) of Pinyon and Juniper.

Mixtures of pinyon and juniper with 300 or more trees per acre in 14 to 18 inch rainfall areas can be burned on hot, windy days if prepared properly (Truesdell, 1969; Blackburn and Bruner, 1975). However, closed stands of juniper are almost impossible to burn (Blackburn and Bruner, 1975) and would probably require winds in excess of 35 mph to carry a fire. As the proportion of pinyon to juniper increases and density increases, the stands are easier to burn (Truesdell, 1969; Blackburn and Bruner, 1975).

Recommendation: Where firebrands are not a problem on a hot day (i.e., burning into the Grand Canyon or on top of a mesa), prepare dense stands of pinyon and juniper for burning in March or April by clearing a strip 20 to 50 feet wide and pushing a windrow against the green trees every 0.25 mile on the windward side and letting the material cure for 60 to 90 days. Then, in late June or early July, burn when temperatures vary from 80 to 95° F, relative humidity is 4 to 8 percent, and winds exceed 8 mph (Truesdell, 1969; Blackburn and Bruner, 1975).

Where firebrands are of concern or the pinyon-juniper stands are predominantly juniper, a more acceptable method of killing trees in closed stands may be to chain, burn, and seed (Aro, 1971; Stinson, 1978). Two or three months after chaining, pinyon and juniper can be burned with little risk when the wind is blowing into an untreated closed stand or a recently treated area with little fine fuel. Conditions for such burning where juniper is predominant should be when the air temperature is 90 to 100° F, relative humidity is less than 10 percent, and wind is 8 to 10 mph (Stinson, 1978). If pinyon pine is a major component, lower temperatures and less wind might be desired, or at least the lee sides of the area ought to be burned out (200 feet) during the morning hours when the fire danger is low (Stinson, 1978).

It takes large crews to do this latter kind of burning because much of the material is in piles or windrows. Advantages of burning chained areas is to remove the trash and young trees, which provide an ideal microenvironment for the establishment of pinyon and juniper seedlings (Meagher, 1943), and to provide a good seedbed.

Another alternative for dense stands with mixtures of pinyon and juniper would be to use chaining as a method to construct firelines (Davis, 1976). The necessary width is not known, but presumably a 100 to 200-foot line would be adequate because glowing embers should not be a problem. Only the flaming embers would be of concern. The lines could be chained in the winter and then burned under moderate conditions in the spring or summer when surrounding vegetation is green (Davis, 1976). Weather with temperatures of 60 to 75° F, wind speed less than 8 mph and relative humidity above 25 percent should

be adequate for burning such firelines, although this has not been documented. It would seem preferable to burn under cool conditions so that most of the manpower force could be used to light the dead material rather than to patrol for spotfires.

After the firelines have been burned out, then the windrows (also prepared in winter) on the upwind side could be lit on a dry, hot, windy day in June or July. Air temperatures should be 80 to 95° F, humidity 4 to 8 percent, and wind speed in excess of 8 mph.

Mixture of Pinyon-Juniper and Sagebrush

Mixtures of sagebrush and pinyon-juniper are common throughout the Great Basin. Dense patches of pinyon-juniper and sagebrush that may vary in size from 5 to 60 acres can easily be burned without preparing firelines (Bruner and Klebenow, 1978).

Recommendation. Klebenow and Bruner (1976) have found that mixtures of pinyon-juniper and sagebrush with a total shrub and tree cover of 45 to 60 percent can be burned when spring air temperatures vary from 60 to 75° F, relative humidity is below 25 percent, and maximum wind speeds vary from 5 to 25 mph. They recommend using the "White Pine County Formula" to determine whether or not to burn (Bruner and Klebenow, 1978) where,

Index = Maximum Wind (mph) + Shrub and Tree Cover (%) + Air Temperature (°F).

If the index is 110 or higher, a fire will carry and will kill large pinyon and juniper trees. If the index is above 130, it is too dangerous to burn.

THE ROLE AND USE OF FIRE IN SAGEBRUSH-GRASS AND PINYON-JUNIPER PLANT COMMUNITIES

A-STATE-OF-THE-ART-REVIEW

Sagebrush-Grass Communities

Introduction

Sagebrush-grass vegetation covers at least 96.5 million acres in the western United States, as estimated by the U.S. Forest Service in 1936, but considerably less than the 270 million acres estimated by Beetle in 1960 (Tisdale et al, 1969). The largest contiguous area lies in eastern Oregon, southern Idaho, southwestern Wyoming, northern Utah, and northern Nevada, although sagebrush-grass communities are widely distributed in western North America (Vale, 1975). Generally, sagebrush-grass communities occur below the pinyon-juniper zone in Nevada, Utah, and Oregon, but in the absence of a pinyon-juniper zone, sagebrush-grass vegetation will border curlleaf mahogany (*Cercocarpus ledifolius*), oak-brush (*Quercus gambelii*), ponderosa pine (*Pinus ponderosa*), or Douglas-fir (*Pseudotsuga menziesii*).

Fire History

Before the influence of man, the average frequency of fire across contiguous units of sagebrush-grass communities in northern Yellowstone National Park was 32 to 70 years (Houston, 1973). Within a large general area, however, some kind of fire occurred at least every 17 to 41 years.

Dating all fires that occurred within a locale, Houston theorized that the frequency of fire in sagebrush communities was 20 to 25 years. This estimated frequency was based on the thinking that the record of fire scars for any one tree underestimated the frequency of fire because not all trees were scarred by every fire. In view of his findings that many similar fire dates occurred among trees, which were not common to all, one may also reason that once an area was burned during a dry period it is unlikely that these areas would have sufficient fuel to reburn for several years.

Based on the vigorous response of horsebrush (*Tetradymia canescens*) to fire and the 30 plus years that are needed for it to decline to a low level after a fire (Harniss and Murray, 1973), we feel that an acceptable frequency of fire would be about 50 years. If fires occurred every 20 to 25 years, as Houston implies, many sagebrush-grass communities would be dominated by horsebrush and rabbitbrush.

Distribution, Climate, Soils, and Vegetation

Elevation of the major sagebrush-grass zone is from 2,000 to 7,000 feet although it occurs below 1,000 feet in south-central Washington and British Columbia and mixes with all vegetative zones to varying degrees above 7,000 feet. This includes the sub-alpine herbland. Annual precipitation is 8 to 20 inches (Tisdale et al, 1969). Soil texture varies from loamy sand to clay (Tisdale et al, 1969), which interacts with precipitation and elevation to form many distinct combinations of sagebrush-grass communities. Most soils are derived from basalt, although considerable areas have soils derived from rhyolite (southeastern Oregon and Nevada), loess, lacustrine, alluvium, and limestone.

Three subspecies of big sagebrush--basin big sagebrush (*Artemisia tridentata* subsp. *tridentata*), Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*), and mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*)--dominate this zone. Basin big sagebrush (3.5 to 15 feet tall) and Wyoming big sagebrush (1.5 to 2.5 feet tall) are the dominants from 2,000 to 7,000 feet, with the latter being the most drouth tolerant and the most palatable (McArthur et al, 1974). Basin big sagebrush occupies a 10 to 16-inch precipitation zone on deep, well drained alluvial soils, whereas Wyoming big sagebrush occupies an 8 to 12-inch precipitation zone on shallow soils (Tisdale et al, 1969). Mountain big sagebrush (2.5 to 4 feet tall) is the most mesic subspecies and can be found at elevations from 5,000 to 10,000 feet (McArthur et al, 1974) where precipitation varies from 14 to 20 inches per year. Generally, it is found above 6,500 feet.

Other species of sagebrush in decreasing order of economic importance are low sagebrush (*A. arbuscula*), three-tip sagebrush (*A. tripartita*), black sagebrush (*A. nova*), silver sagebrush (*A. cana* subsp. *viscidula* and *A. cana* subsp. *bolanderii*), alkali sagebrush (*A. longiloba*), Bigelow sagebrush (*A. bigelowii*), and scabland sagebrush (*A. rigida*) (Tisdale et al, 1969; McArthur et al, 1974). The first three generally grow below 6,000 feet elevation, although they can occur at higher elevations. Low sagebrush occurs on shallow soils or those that possess a restrictive B horizon largely in southern Idaho, Nevada, southeastern Oregon, and northeastern California (Fosberg and Hironaka, 1964). Three-tip sagebrush occurs east of this region on very mesic or dry soils in a precipitation zone of 10 to 16 inches. Black sagebrush is usually associated with calcareous soils on dry sites, but can occur as high as the Douglas-fir zone in eastern Idaho. Silver sagebrush occurs primarily in spring-flooded bottomlands. All species except three-tip sagebrush and silver sagebrush are nonsprouters. Three-tip sagebrush is a weak sprouter and silver sagebrush is a vigorous sprouter.

Major shrubs associated with big sagebrush include antelope bitterbrush (*Purshia tridentata*), horsebrushes (*Tetradymia* spp.), rabbitbrush (*Chrysothamnus* sp.), and broom snakeweed (*Xanthocephalum sarothrae*).

Spiny hopsage (Grayia spinosa) and mormon tea (Ephedra nevadensis) are sporadically present in the lower rainfall areas near the Salt Desert.

Dominant grasses include bluebunch wheatgrass (Agropyron spicatum), Idaho fescue, needle-and-thread (Stipa comata), Thurber needlegrass (Stipa thurberiana), and Indian ricegrass (Oryzopsis hymenoides). All of these species or only one may be present in a particular understory. Needle-and-thread and Indian ricegrass dominate sandy soils throughout the sagebrush-grass zone. On other soils, bluebunch wheatgrass dominates areas with moderate precipitation (9 to 14 inches) and Idaho fescue dominates the most mesic sites (generally more than 14 inches of precipitation). Temperature interacts with precipitation so the moisture threshold that separates bluebunch wheatgrass from Idaho fescue can vary from 12 to 16 inches of precipitation annually. Thurber needlegrass occurs on medium textured soils in an 8 to 12-inch precipitation zone. Sandberg bluegrass (Poa sandbergii) and bottlebrush squirreltail (Sitanion hystrix are the most common subdominant bunchgrasses. Junegrass (Koeleria cristata) and other Poa sp. are also often present if the annual precipitation is above 11 inches. Rhizomatous grasses that occupy localized areas include thickspike wheatgrass (Agropyron dasystachyum), plains reedgrass (Calamagrostis montanensis), and riparian wheatgrass (Agropyron riparium). Cheatgrass (Bromus tectorum), an introduced annual, occupies millions of acres on disturbed ranges (Klemmedson and Smith, 1964), but medusahead (Taeniatherum asperum), another introduced annual, occupies the disturbed clay sites which have well developed profiles (Dahl, 1966).

Forbs are present in great variety and abundance in climax communities where the precipitation is in excess of 11 to 12 inches per year. They may account for as much as 50 percent of the herbaceous production in eastern Idaho, but only 5 to 15 percent of the herbaceous vegetation in eastern Oregon. This is why chemicals, at least in our opinion, are undesirable to manage sagebrush-grass communities in eastern Idaho where balsamroot (Balsamorhiza sagittata) and lupine (Lupinus sp.) are typically the most abundant forbs. In eastern Oregon, groundsel (Senecio sp.), tapertip hawksbeard (Crepis acuminata), western yarrow (Achillea millefolium), and loco weed (Astragalus sp.) are the most common forbs and recover within 3 to 4 years after the use of herbicides (Forrest A. Sneva, Squaw Butte Station, Burns, Oregon).

Ecological Effects of Fire

The effect of fire on grasses depends largely on their growth form and season of burning. Bunchgrasses with densely clustered culms, such as Idaho fescue and needle-and-thread, can be severely harmed by fire (Blaisdell, 1953; Wright, 1971), and even more so if burned during June or July (Wright, 1971). Late summer or fall burns are the least harmful. The reason that these plants are killed so easily is that their dense culms will burn for 2 to 3 hours after a fire passes. Temperatures as high as 1,000° F will be reached 45 minutes after a fire has passed

(Wright, 1971). Thus, many plants often die or have only a few culms that survive, regardless of the intensity of the passing fire. Threadleaf sedge (Carex filifolia) also has a compact growth form and is severely harmed by fire (Vallentine, 1971). Preliminary research in eastern Oregon indicates that Idaho fescue is not as sensitive to fire as it is in southern Idaho. Carlton M. Britton, Squaw Butte Experiment Station, Burns, Oregon, and David L. Caraher, Crooked River National Grasslands, Prineville, Oregon, feel that Idaho fescue will recover in 2 to 3 years if burned when the soil is moist.

Bluebunch wheatgrass, bottlebrush squirreltail, and the crested wheatgrasses (Agropyron cristatum, A. desertorum, and A. sibericum) are less susceptible to fire than Idaho fescue or Stipa sp. (Blaisdell, 1953; Conrad and Poulton, 1966; Wright, 1971; Vallentine, 1971) because they are composed primarily of coarse stems with some leafy material. They burn very quickly with little heat going below the soil surface (Wright, 1971). Often Sandberg bluegrass and bottlebrush squirreltail are small plants in climax communities, which aids their survival after a fire (Wright and Klemmedson, 1965). Thus, they usually increase in abundance after a fire. All rhizomatous grasses, such as thickspike wheatgrass and plains reedgrass, increase immediately after a fire in relation to other species (Blaisdell, 1953). Production from rhizomatous grasses on a burn will be above that on control plots for about 30 years (Harniss and Murray, 1973).

Bluebunch wheatgrass will return to preburn production in 1 to 3 years (Blaisdell, 1953; Moomaw, 1957; Daubenmire, 1963; Conrad and Poulton, 1966; Uresk et al, 1976); needle-and-thread in 3 to 8 years, depending on site (Blaisdell, 1953; Dix, 1960; personal observations); and Idaho fescue in 2 to 12 or more years depending on soil moisture, season, and intensity of the fire (Blaisdell, 1953; Conrad and Poulton, 1966; Harniss and Murray, 1973; Unpublished data by C. M. Britton, Squaw Butte Experiment Station, Burns, Oregon). The response of prairie junegrass (Koleria cristata) to fire is similar to that of needle-and-thread. Cusick bluegrass (Poa cusickii) is reduced 50 percent the first growing season after burning (Uresk et al, 1976). Indian ricegrass (Oryzopsis hymenoides) is only slightly damaged by fire (Vallentine, 1971).

Repeated burning every few years or burning in early summer will deplete a stand of perennial grasses and allow annual grasses, chiefly cheatgrass (Bromus tectorum), to increase sharply (Pickford, 1932; Wright and Klemmedson, 1965). Once sagebrush-grass is depleted to where it has no perennial plant cover, secondary succession goes from Russian thistle (Salsola kali) to mustard (Sisymbrium and Descurainia sp.) to cheatgrass in a period of 5 years (Piemeisel, 1951). June and July burns reduced cheatgrass plant numbers to 14 and 11/ft^2 compared to 41, 45, and 124 plants/ft^2, respectively on August, October, and November burns in Boise, Idaho (Pechanec and Hull, 1945). This is only a temporary setback for cheatgrass at a time of the year when climax

perennials can be killed by fire (Wright and Klemmedson, 1965). Reclamation of such areas can only be achieved by chemical-fallow techniques (Eckert and Evans, 1967) or plowing and then seeding. Most seeding has been done with wheatgrasses (Hull, 1971). Fairway wheatgrass (Agropyron cristatum), crested wheatgrass (A. desertorum), and siberian wheatgrass (A. sibericum) are well adapted to this zone. Fairway wheatgrass is best adapted to moderately mesic sites and siberian wheatgrass is best adapted to the driest sites in the 8 to 12-inch precipitation zone.

Areas that are primarily sagebrush and cheatgrass can be successfully seeded directly after fire if the fire burns hot enough to consume the sagebrush plants (Young et al, 1976). Otherwise much live cheatgrass seed remains and chemical-fallow techniques (Eckert and Evans, 1967) or plowing after spring germination is desirable before drilling with perennial wheatgrasses.

Fall burning does not harm most forbs because many of them are dry and often disintegrated by this time. However, some forbs remain green and are very susceptible to fire (Table 1). Unpublished data in Utah shows that late summer or fall burning can kill Indian paintbrush (Castilleja angustifolia) (Neil C. Frischknecht, Intermountain Forest and Range Experiment Station, Ephraim, Utah).

After 12 years, Blaisdell (1953) found that only the heavy sagebrush-grass burn supported more forbs than the control. By the end of 30 years, forbs had returned to preburn levels (Harniss and Murray, 1973), although both burned and unburned plots contained at least five times as many forbs as before the burn.

Fires can have a devastating and long-lasting effect on shrubs in sagebrush-grass communities. Big sagebrush, a nonsprouter, is highly susceptible to fire (Pickford, 1932; Blaisdell, 1953). Blaisdell found that the production of this species on burned areas in Idaho was only 10 percent of that on the control 12 years after the burn, but was near preburn levels 30 years after the burn (Harniss and Murray, 1973). Some areas, however, recover more quickly. These differences may be related to season of burn as it affects seed production (Johnson and Payne, 1968), summer precipitation, and completeness of burn. Three-tip sagebrush is also damaged by fire, but some plants resprout (Blaisdell, 1953).

Antelope bitterbrush is severely damaged by burning (Blaisdell, 1953; Pechanec et al, 1954; Countryman and Cornelius, 1957; Nord, 1965). In Idaho 12 to 15 years after a burn, antelope bitterbrush was still only producing 50 to 60 percent as much as the control (Blaisdell, 1953). If soil is wet at the time of burn or shortly after the burn, resprouting of this bitterbrush occurs regularly (Blaisdell, 1953; Blaisdell and Mueggler, 1956; Nord, 1965), except on pumice soils in eastern Oregon. If the plants resprout, they will regain original growth in 9 to 10 years (Blaisdell, 1953). Where fires are not followed by rain, antelope

bitterbrush seldom sprouts. However, in southern California, desert bitterbrush (P. glandulosa) resprouts vigorously and abundantly (Nord, 1965) even when postfire rains are lacking.

Table 1 Susceptibility of Forbs to Fire by Three Classifications at Dubois, Idaho (Pechanec et al, 1954).

Severely damaged	Slightly damaged	Undamaged
Antennaria dimorpha	Astragalus sp.	Achillea lanulosa
Antennaria microphylla	Castilleja angustifolia	Allium sp.
Arenaria uintahensis	Crepis acuminata	Arnica fulgens
Erogeron engelmannii	Geranium viscosissimum	Balsamorhiza sagittata
Eriogonum caespitosum	Lupinus caudatus	Commandra umbellata
Eriogonum heracleoides	Penstemon radicosus	Erigeron corymbosus
Phlox canescens	Sphaeralcea munroana	Lupinus leucophyllus
		Phlox longifolia
		Senecio integerrimus
		Sisymbrium linifolium
		Zygadenus paniculatus

Other species severely damaged by fire include cliffrose (Cowania mexicana), curlleaf mountain mahogany (Cercocarpus ledifolius), granite gilia (Gilia pungens), and broom snakeweed (Xanthocephalum sarothrae) (Pechanec et al, 1954; Vallentine, 1971). Mountain snowberry (Symphoricarpos oreophilus) appears to be somewhat harmed by burning but shows no change 15 years after burning (Pechanec et al, 1954; Blaisdell, 1953). Oregon grape (Mahonia repens) is favored by burning, especially after intense fires (Blaisdell, 1953).

Rabbitbrush (Chrysothamnus sp.), a common genus in the sagebrush-grass zone, is usually enhanced by fire (Cottam and Stewart, 1940; Blaisdell, 1953; Countryman and Cornelius, 1957; Chadwick and Dalke, 1965; Young and Evans, 1974). An exception to this general response is based on two observations by Robertson and Cords (1957) for rubber rabbitbrush (Chrysothamnus nauseosus). This species showed no recovery 2 years after a burn on September 3, 1942 near Mono Lake, California and after a burn on November 7, 1943 near McGill, Nevada. However, a burn in the latter area was repeated the following year on the same date and 95 percent of the plants resprouted. Generally, this is what we expect to happen, but obviously there are conditions under which rubber rabbitbrush can be killed.

Chrysothamnus puberulus, C. bloomeri, C. lanceolatus, and C. viscidiflorus all resprout vigorously. Generally, production is reduced for 1 to 3 years after burning, then it increases dramatically. On the U.S. Sheep Station near Dubois, Idaho, burning reduced production

59 percent the first year after burning (Blaisdell, 1953). Three years after burning, production doubled and was tripled at the end of 12 years (Blaisdell, 1953). Similarly, Chadwick and Dalke (1965) found that the cover of C. viscidiflorus had increased four to nine times on 8 to 18-year-old burns on sandy soils in northeast Idaho. Production of C. bloomeri doubled 5 years after a burn in northern California (Countryman and Cornelius, 1957). In western Nevada, Young and Evans (1974) found that green rabbitbrush (C. viscidiflorus var. viscidiflorus) continued to dominate burns and reestablish itself periodically for 15 years. Communities 40 to 50 years old were dominated by big sagebrush and contained reduced populations of green rabbitbrush.

Production of horsebrush (Tetradymia canescens) was reduced about 50 percent the first year after burning, but doubled at the end of 3 years (Blaisdell, 1953). At the end of 12 years, it had increased five-fold. After 30 years, many of these plants were dying out, but their production was still 60 percent above the control (Harniss and Murray, 1973). Fire greatly enhances the dominance of this species.

Desirable shrubs, such as serviceberry (Amelanchier alnifolia), snowbrush caanothus (Ceanothus velutinus), and true mountain mahogany (Cercocarpus montanus) are not damaged by fire (Vallentine, 1971).

Management Implications

Prescribed fire can be a useful tool in many big sagebrush communities if the fires are carefully planned and livestock use after the burn is delayed for two growing seasons. Removal of thick sage-brush by fire will greatly enhance movement of livestock, reduce competition, and result in increased yields of grasses and forbs. However, depending on the vegetation, fires should not be too frequent and should be planned in early spring or after late summer. Caution should be exercised where antelope bitterbrush is dominant and where there are high resident populations of horsebrush or rabbitbrush. Where forbs are abundant or sagebrush is thick, fire is highly preferred over chemical treatments as a management tool.

It appears that much burning can be done in the sagebrush-grass region without firelines. This is especially true where patches of big sagebrush grow in swales or small ravines among low sagebrush. Fires will not carry in low sagebrush when winds are 20 mph, so they can be used as firebreaks when the big sagebrush is being burned. This is highly desirable because only the most productive sites are being burned. Similarly, early spring burning can be done at higher elevations in pure stands of big sagebrush where snow patches can be used as firelines. This is desirable for game management, but livestock should be carefully managed because animals will concentrate on the open areas.

Fires in combination with seeding can be used to suppress medusa-head, but they cannot be used very successfully in combination with

seeding where cheatgrass is dominant, unless it has an overstory of sagebrush. Most cheatgrass areas will need to be treated with chemicals or plowed and then seeded if perennials are desired. Fire will not encourage native perennials in pure stands of cheatgrass, nor will pure stands of cheatgrass invert back to native perennials with rest.

State of the Art

We know generally how most shrubs and herbaceous species are going to respond to fire in sagebrush-grass communities, but more information is needed on bluebunch wheatgrass, Idaho fescue, and the big sagebrush subspecies. Fire intensity, season of burn, plant size, and soil moisture status should be evaluated at a variety of bluebunch wheatgrass and Idaho fescue locations for several years. More long-term data following fires is badly needed for Idaho fescue.

Big sagebrush subspecies will sometimes invade burned areas rapidly and sometimes very slowly. McDonough and Harniss (1974) have done some work on the germination requirements of big sagebrush but more studies are needed. Timing of burns in relation to seed maturity of sagebrush, residual seed supply in soil after various intensities of heat, and response of sagebrush seed to soil moisture over a period of years all need to be evaluated. Seed dispersal distance of sagebrush plants has been studied by Frischknecht (1962). He found that the mean distance of maximum spread of big sagebrush seed was 42 feet from parent plants.

We also need more research on spring vs. fall burns. Where forbs are not important in plant communities, early spring burning may be more desirable for bunchgrasses than later summer or fall burns.

Prescription data for sagebrush-grass burns have been given by Pechanec et al (1954) and more recently by Ralphs et al (1976). Nevertheless, the data are meager. We will need more data on prescribed burning techniques before fire can be used economically. Desired width of firelines is still a question, and the potential for spotfires in sagebrush-grass communities needs to be more thoroughly documented, although sagebrush is less volatile (Powell, 1970) than chamise and pinyon-juniper.

Pinyon-Juniper Communities

Introduction

The pinyon-juniper association covers from 43 to 76 million acres in western North America, depending on whether you use Kuchler's (1964) map of potential pinyon-juniper woodland (the lower figure) or the earlier Senate Document 199 (Clapp et al, 1936) where all western lands then having juniper, with or without pinyon pines, were included. West et al (1975) have taken a liberal definition of pinyon-juniper woodlands and included both Kuchler's "juniper-pinyon woodlands" and

"juniper steppe" types, plus the areas within the Great Basin sagebrush, sagebrush-grass steppe, and the Trans-Pecos shrub savannah. Leaving out the juniper woodlands in Texas, the figure by West et al (1975) for the western United States is 75 million acres. These lands are located below the oakbrush (Quercus gambelii) and ponderosa pine (Pinus ponderosa) zones, but above the sagebrush (Artemisia sp.) or grassland areas where juniper, more xeric than pinyon, is continually spreading.

Fire History

The historic role of fire in controlling the distribution of pinyon-juniper, particularly juniper, cannot be separated from the effect of drouth and competition (Leopold, 1924; Johnsen, 1962). All occurred simultaneously and seemed to have played a complementary role in limiting the distribution of juniper before domestic livestock were a factor. However, drouths and competition from grass probably served only to slow the invasion and growth of junipers in adjacent grasslands, since the trees are easily established during wet years (Johnsen, 1962; Smith et al, 1975), especially where shade is present (Meagher, 1943). Then fire, occurring about every 19 years (Leopold, 1924) or possibly as long as 30 years, kept the junipers restricted to shallow, rocky soils and rough topography (Arend, 1950; Burkhardt and Tisdale, 1969). For the last 70 years, however, heavy livestock grazing has reduced grass competition as well as fuel for fires and has permitted pinyon and juniper to invade adjacent communities rapidly and unchecked.

The above leads one to believe that fire has tremendous potential as a tool to reclaim grasslands that have been invaded by juniper and where overgrazing has led to closed stands of pinyon-juniper, but not in rough breaks where the fine fuels are inadequate to carry a fire (Burkhardt and Tisdale, 1969; O'Rourke and Ogden, 1969). Aro (1971) concluded that burning was the most effective and least expensive method to convert pinyon-juniper to grassland.

Blackburn and Bruner (1975) mentioned that prescribed burning has been used in pinyon-juniper communities several ways: (1) burning slash and debris left after the use of other methods of control; (2) burning individual trees where neither the trees nor the understory plants are dense enough to carry fire; (3) burning grassland or sagebrush-grassland to kill invading trees; and (4) broadcast burning mature trees. Broadcast burning has also been used to kill trees less than 4 feet tall in grasslands (Jameson, 1962; Dwyer and Pieper, 1967).

Distribution, Climate, Soils, and Vegetation

True pinyon-juniper woodlands extend from the east slope of the Sierra Nevada Mountains, eastward throughout mountains of the Great Basin in Nevada and Utah, and on both flanks of the Rocky Mountains in Colorado (as well as mesas of the Colorado Plateau and interior valleys), then southward into Arizona, New Mexico, and northern Mexico (Rasmussen,

1941; Johnsen, 1962). Dense stands of juniper alone that join the pinyon-juniper woodlands extend further north into eastern Oregon and southern Idaho and Wyoming.

Pinyon-juniper woodlands are generally found at elevations from 4,500 to 7,500 feet (Springfield, 1976), but they are best developed between 5,000 and 7,000 feet (Woodbury, 1947). Nevertheless, pinyon-juniper may be found growing from 2,500 to 3,000 feet in the upper parts of deserts (Johnsen, 1962; Franklin and Cyrness, 1969) to 9,000 feet in ponderosa pine forests (Lanner, 1975). The highest elevation for pinyon-juniper woodland is nearly 10,000 feet in the White Mountains of California where the Sierra Nevada Mountains create an extreme rain shadow effect (St. Andre et al, 1965). The upper altitudinal limit of the pinyon-juniper zone is determined by low temperature and the lower range by a deficiency in moisture (Pearson, 1920).

Annual precipitation varies from 10 to 15 inches over most of the pinyon-juniper zone where stands are open (Woodbury, 1947), but dense stands may receive 16 to 22 inches of rain and snow (Springfield, 1976). On xeric sites at high elevations, annual precipitation of pinyon-juniper communities may be as high as 26 inches (Pearson, 1931). Pinyon (Pinus edulis and P. monophylla) is usually most abundant at the higher elevations of the pinyon-juniper zone with a mixing of pinyon and juniper at mid elevations (Reveal, 1944; West et al, 1975; Springfield, 1976). Since pinyon is very susceptible to fire (Leopold, 1924), as well as the more mesic of the two genera, fire is probably an additional factor that keeps pinyon out of the lower elevations.

Distribution of the pinyon-juniper association is not limited by soil (Pearson, 1931; Springfield, 1976). The trees grow on residual and transported soils derived from sandstone, limestones, basalt, granite, and mixed alluvium (Springfield, 1976). Soil textures vary from stony, cobbly, and gravelly loams to clay loam and clay, and depth from shallow to deep (Springfield, 1976), but the best stands of pinyon are found on course gravel, gravelly loam, or coarse sands (Phillips, 1909). The soils are generally calcareous and alkaline, but juniper can grow easily on acid soils down to a pH of 4.7 (Arend, 1950). Except for these soils derived from basalt, most are low in fertility (Howell, 1941; Springfield, 1976) and often shallow and rocky.

Dominant tree species of the pinyon-juniper woodlands are Utah juniper (Juniperus osteosperma), one-seed juniper (J. monosperma), Rocky Mountain juniper (J. scopulorum), alligator juniper (J. deppeana), doubleleaf pinyon (Pinus edulis), and singleleaf pinyon (P. monophylla). Doubleleaf pinyon is associated with the southern Rocky Mountains and extends westward to the eastern edge of the Great Basin. Throughout the Great Basin, eastern slope of the Sierra Nevada Mountains, and western portions of Arizona, singleleaf pinyon is associated primarily with Utah juniper.

Utah juniper is the most important species in the pinyon-juniper woodland (Fanner, 1975). It is distributed in northern Arizona, Utah, Nevada, and parts of California. One-seed juniper extends from central Colorado to central Arizona and is widely distributed throughout most of New Mexico. A little occurs in the Palo Duro Canyon of west Texas. Alligator juniper, a sprouting species, is also widespread in the Southwest. It is abundant in Mexico and reaches its northern limits in north-central Arizona and New Mexico. Rocky Mountain juniper occurs only at the higher elevations of the pinyon-juniper woodland (Fanner, 1975).

Outside of the pinyon-juniper woodland, western juniper (*J. occidentalis*) is very abundant in eastern Oregon. East of New Mexico, additional species of juniper such as redberry juniper (*J. pinchoti*), a sprouting species, Ashe juniper (*J. ashei*), and eastern red cedar (*J. virginiana*) are abundant in some areas. These species are often associated with rocky slopes, such as escarpments, ridges, or rimrocks throughout the Great Plains (Wells, 1970), and alkaline soils, such as the Edwards Plateau in central Texas. From the rocky areas where juniper is considered to be the climax in the plains, trees spread rapidly into the surrounding grasslands in the absence of fire. Eastern red cedar is the most extensive species and occurs from Texas northeastward throughout most of the eastern United States.

Herbaceous species vary considerably throughout the pinyon-juniper zone. On the eastern flank of the Rocky Mountains in New Mexico, blue grama (*Bouteloua gracilis*) is the dominant herb understory with some sideoats grama (*B. curtipendula*) and wolftail (*Lycurus phleoides*) and a few forbs often intermixed (Pieper et al, 1971). In north-central Arizona, blue grama and sideoats grama remain as dominant grasses, but prairie junegrass (*Koeleria cristata*), bottlebrush squirreltail (*Sitanion hystrix*), muttongrass (*Poa fendleriana*), and black dropseed (*Sporobolus interruptus*) are important components (Clary, 1971). Other sites include desert needlegrass (*Stipa speciosa*) (Thatcher and Hart, 1974), red three-awn (*Aristida longiseta*), ring muhly (*Muhlenbergia torreyi*) (Jameson and Reid, 1965), and western wheatgrass (*Agropyron smithii*) (Clary and Morrison, 1973). Forbs and half shrubs make up about 50 percent of the herbaceous composition in north-central Arizona. Broom snakeweed (*Xanthocephalum sarothrae*), sulfur eriogonum (*Eriogonum cognatum*), plumeweed birdbeak (*Cordylanthus wrightii*), and goldeneye (*Viguiera* sp.) are dominants (Clary, 1971).

Northward, warm season grasses drop out of the understory. In southwestern Colorado, in Mesa Verde National Park, the meadow stage (4 years after burning) is dominated by Indian ricegrass (*Oryzopsis hymenoides*), bottlebrush squirreltail, and muttongrass (Erdman, 1970). Forbs and shrubs are also present at various stages of succession after burning. In Utah, bluebunch wheatgrass (*Agropyron spicatum*) and western wheatgrass are the most abundant grasses with lesser amounts of

Sandberg bluegrass (Poa sandbergii), bottlebrush squirreltail, and Indian ricegrass (Barney and Frischknecht, 1974). Forbs are a minor component.

In Nevada, a variety of sources (Blackburn et al, 1969; Jensen, 1972; Klebenow et al, 1976) indicate that common grasses include bottlebrush squirreltail, Sandberg bluegrass, needle-and-thread (Stipa comata), Great Basin wildrye (Elymus cinereus), and cheatgrass (Bromus tectorum). Other grasses include western wheatgrass, Indian ricegrass, and Thurber needlegrass (S. thurberiana). Forbs vary widely in species and abundance but can include Lupinus sp., Phlox mentzelia sp., Eriastrum sp., Castilleja sp., Machaeranthera sp., Argemone sp., Sphaeralcea sp., Nicotiana sp., Lygodesmia sp., and Chenopodium sp.

Further north in eastern Oregon, bluebunch wheatgrass and Idaho fescue (Festuca idahoensis) are the dominant grasses (Franklin and Dryness, 1969). Sandberg bluegrass and Thurber needlegrass are common. Other grasses include bottlebrush squirreltail, needle-and-thread, cheatgrass, annual fescue (Festuca octoflora), and prairie junegrass. Forbs are not very abundant but the most common perennial forbs are Agoseris sp., Achillea millifolium, Eriophyllum lanatum, Astragulus sp., Erigeron linearis, and Lupinus sp.

Herbage yields of pinyon-juniper stands can vary considerably depending on surface texture of soil and stage of succession (Thatcher and Hart, 1974). Soils with a vesicular, massive, or platy surface layer may have very little grass regardless of the stage of plant succession (Thatcher and Hart, 1974). However, a reasonable average herbage yield for plant communities with moderate amounts of pinyon-juniper seems to be 600 lb/acre (Jameson and Reid, 1965; Jensen, 1972; Pieper et al, 1971; Clary, 1971). Yields on good soils with good precipitation can be as high as 1,400 lb/acre (Pieper et al, 1971; Springfield, 1976).

Shrubs that dominate the understory of pinyon-juniper include big sagebrush (Artemisia tridentata), black sagebrush (A. nova), antelope bitterbrush (Purshia tridentata), shrub live-oak (Quercus turbinella), cliffrose (Cowania mexicana), Gambel's oak (Quercus gambelii), serviceberry (Amelanchier sp.), and true mountain mahogany (Cercocarpus montanus). Other shrubs that are associated in various amounts with pinyon-juniper include fringed sagebrush (A. frigida), Wright silktassel (Garrya wrightii), currant (Ribes cereum), desert peach (Prunus andersonii), mountain lover (Pachistima myrsinites), skunkbush sumac (Rhus trilobata), ephedra (Ephedra sp.), curlleaf mountain mahogany (C. ledifolius), chokecherry (Prunus virginiana), mockorange (Philadelphus lewisi), pointleaf manzanita (Arctostaphylos pungens), winterfat (Ceratoides lanata), snowberry (Symphoricarpos vaccinoides), algerita (Berberis fremonti), Wright eriogonum (Eriogonum wrightii), rabbitbrush (Chrysothamnus nauseosus), Apache plume (Fallugia paradoxa), blackbrush (Coleogyne ramosissima), fourwing saltbush (Atriplex

canescens), broom snakeweed, dalea (Dalea sp.), horsebrush (Tetradymia canescens), and yucca (Yucca sp.). This wide variety of shrubs reflects the many different plant communities which pinyon-juniper buffers against and has been taken from various references (Arnold et al, 1964; Dwyer and Pieper, 1967; Blackburn et al, 1969; O'Rourke and Ogden, 1969; Blackburn and Tueller, 1970; Erdman, 1970; Aro, 1971; Clary, 1971; Barney and Frischknecht, 1974; Klebenow et al, 1976; Springfield, 1976; Young and Evans, 1976).

Ecological Effects of Fire

Pinyon and Juniper

The effect of fire on living pinyon and nonsprouting juniper trees depends largely upon the height of trees, herbaceous fuel, weather conditions, and season. In open pinyon-juniper stands with an understory of 700 to 1,000 lb/acre of fine fuel, Jameson (1962) and Dwyer and Pieper (1967) found that pinyon and juniper were easily killed by spring fires if trees were less than 4 feet tall, when air temperature was 70 to 74° F, relative humidity 20 to 40 percent, and wind speed is 10 to 20 mph. Lower air temperatures in January (49 to 54° F), relative humidity 44 percent, and wind of 6 to 8 mph caused a very spotty burn in which crown kill varied from 30 to 70 percent of trees 2 to 4 feet tall, but 70 percent of trees died (Jameson, 1962). A wildfire in June with an air temperature of 97° F, wind 10 to 15 mph, and relative humidity 17 to 25 percent assured a 100 percent kill of all trees less than 4 feet tall, but was no more effective on taller trees than when air temperatures were 70 to 74° F (Jameson, 1962).

Trees greater than 4 feet tall in open pinyon-juniper stands are difficult to kill unless you have excess accumulations of fine fuel beneath the trees. On the wildfire studied by Dwyer and Pieper (1967), only 24 percent of the pinyon and 13.5 percent of the juniper which exceeded 4 feet died. Jameson (1962) found that most juniper over 4 feet tall only had a 30 to 40 percent crown kill, unless tumbleweeds had accumulated at the base of the trees. Then 60 to 90 percent of the crowns were killed, particularly for trees 8 to 10 feet tall. East of the pinyon-juniper zone in Texas, juniper trees up to 12 feet tall were easily killed when fine fuel was 2,000 lb/acre or higher (Wink and Wright, 1973).

Trees in closed stands of pinyon-juniper with no grass or sagebrush in the understory are difficult to kill because fires won't carry easily (Arnold et al, 1964; Blackburn and Bruner, 1975). Dense stands (495 to 988 trees/acre) in 14 to 18-inch rainfall areas with a mixture of pinyon and juniper can be burned on hot days, but pure stands of juniper are almost impossible to burn (Blackburn and Bruner, 1975). A number of people in the Great Basin area speculate that it would acquire winds over 35 mph to burn pure stands of juniper. Thus, many attempts to burn

such stands have failed (Arnold et al, 1964; Aro, 1971). As the proportion of pinyon to juniper increases and the density increases, the stands are easier to burn (Truesdell, 1969; Blackburn and Bruner, 1975). Such areas are usually burned by clearing an area 20 to 125 feet wide and pushing a windrow against the green trees on the windward side and letting the material cure for 60 to 90 days. Then in June or July, burns are conducted when temperatures vary from 80 to 95° F, relative humidity is 4 to 8 percent, and winds exceed 8 mph (Truesdell, 1969; Blackburn and Bruner, 1975). These burns have been conducted on mesas or next to the Grand Canyon where firebrands were not a problem.

A more acceptable method of killing trees in closed stands of pinyon-juniper may be to chain, burn, and seed (Aro, 1971; Stinson, 1978). Two or three months after chaining, pinyon and juniper can be burned with little risk when the wind is blowing into an untreated closed stand. Conditions for such burning should be when the air temperature is 90 to 100° F, relative humidity less than 10 percent, and wind 8 to 10 mph (Stinson, 1978). It takes large crews to do this kind of burning because much of the material is in piles or windrows. Advantages to burning chained areas is to remove the trash and young trees, which provide an ideal microenvironment for the establishment of pinyon and juniper seedlings (Meagher, 1943), and to provide a good seedbed for grass (Aro, 1971). Seeding grass would be the last step, but is not always necessary (Aro, 1971).

A mixture of sagebrush and pinyon-juniper is common throughout the Great Basin, and it is feasible to burn and kill large pinyon and juniper trees in these communities (Bruner and Klebenow, 1978). To get a fire to carry, Bruner and Klebenow (1978) has proposed the "White Pine County Formula" where:

Index = Maximum Wind (mph) + Shrub and Tree Cover (%) + Air Temperature (° F).

If the index is 110 or higher, a fire will carry and will kill the large pinyon and juniper trees. If the index is above 130, it is too dangerous to burn. Most of the work by Bruner and Klebenow had been done in pinyon-juniper stands with 45 to 60 percent of shrub and tree cover and burned when air temperature was 60 to 75°, relative humidity was below 25 percent, and maximum wind speed was 5 to 25 mph.

Alligator juniper and redberry juniper are the only sprouting species. Smith et al (1975), found that if the tops of redberry juniper trees were removed before they reached 12 years of age, 99 percent mortality could be expected. Older trees were not studied. This data implies that, if subjected to fire every 10 years or so, sprouting species of juniper may have a difficult time invading grasslands. Schroeder (1956) found that 40 percent of alligator juniper trees less than 15 feet tall could be killed by burning individual plants (quoted by Blackburn and Bruner, 1975).

Forbs and Grasses

In Utah, the most abundant annual forbs during the first stage of succession are pale alyssum (*Alyssum alyssoides*), flixweed tansymustard (*Descurainia sophia*), sunflower (*Helianthus annuus*), coyote tobacco (*Nicotiana attenuata*), and Russian thistle (*Salsola pestifer*) (Barney and Frischknecht, 1974). Generally, however, none of these forbs constitute a large amount of cover on pinyon-juniper burns (Arnold et al, 1964; Barney and Frischknecht, 1974). Cheatgrass brome (*Bromus tectorum*) is usually the most abundant annual and has a cover value as high as 12.6 percent on 3-year-old burns. Thereafter, it gradually declines to 0.9 percent over a period of 20 years (Barney and Frischknecht, 1974). On some sites, however, cheatgrass may never show up (Klebenow et al, 1976) which might be used as a guide as to whether some areas can be reclaimed to grasses. In Nevada, tapertip hawksbeard (*Crepis acuminata*) and *Lupinus* sp. increase abundantly after fire (Klebenow et al, 1976). *Balsamorhiza* sp. and *Castilleja* sp. also come back reasonably well (Klebenow et al, 1976).

The composition of perennial grasses varies depending on the location, as discussed earlier. In the northern latitudes west of the Rocky Mountains, cool season grasses dominate with a gradual transition to the dominance of blue grama eastward in the shortgrass plains and southward in central Arizona and New Mexico. Vallentine (1971) has cited a number of authors as to the tolerance of various grasses to fire. Species that are only slightly damaged by fall fires include bluebunch wheatgrass, Indian ricegrass, galleta grass (*Hilaria jamesii*), bottle-brush squirrel tail, Great Basin wildrye, and blue grama. Those moderately affected by fire include prairie junegrass, needle-and-thread, Thurber needlegrass, and three-awns. Species severely affected by fire include ring muhly, sideoats grama, and Idaho fescue. Sandberg bluegrass, cheatgrass, western wheatgrass, and crested wheatgrass are unaffected by fall fires.

Shrubs

Shrubs were mentioned earlier, and there are many species. Vigorous sprouters after fire include serviceberry, Wright silktassel, shrub liveoak, skunkbush sumac, true mountain mahogany, desert bitterbrush, chokecherry, mockorange, winterfat, snowberry, algerita, rabbitbrush, fourwing saltbush, and horsebrush. Weak sprouters include antelope bitterbrush, curlleaf mountain mahogany, snakeweed, mountain lover, yucca, fringed sagebrush, and Wright eriogonum. Antelope bitterbrush and mountain lover are extremely slow in recovering after fire (Nord, 1965; McKell, 1950). Cliffrose is eliminated on burns in Nevada (Klebenow et al, 1976). Nonsprouting species include big sagebrush, black sagebrush, and blackbrush. Nevertheless, these nonsprouting species, except for blackbrush, reestablish themselves quickly from seed. Blackbrush reestablishes itself very slowly (Jenson et al, 1960).

Succession After Fire

The general successional pattern after fire in pinyon-juniper of the Southern Rocky Mountains has been worked out by Arnold et al (1964) and most recently by Erdman (1970) and Barney and Frischknecht (1974). The order of vegetational changes in juniper woodland after fire that were found by Barney and Frischknecht are as follows: Juniper woodland ⟶ fire ⟶ skeleton forest (dead trees and bare soil) ⟶ annual stage ⟶ perennial grass-forb stage ⟶ perennial grass-forb-shrub stage ⟶ perennial grass-forb-shrub-young juniper stage ⟶ shrub juniper stage ⟶ juniper woodland.

Mature stands of juniper (100+ years) consist primarily of 35 percent bare ground, 19 to 60 percent litter which is dominated by the tree overstory that inhibits grass production (Johnsen, 1962), and a few scattered shrubs and perennial and annual grasses (Arnold et al, 1964; Clary, 1971; Barney and Frischknecht, 1974). Erosion is frequently a problem in the bare soils between trees in mature stands (Plummer, 1958). After a fire, juniper seedlings and annuals begin to invade and reach a maximum abundance in the first 3 to 4 years (Arnold et al, 1964; Barney and Frischknecht, 1974). Where partial shade is present, pinyon seedlings can also be abundant (Erdman, 1970). The perennial-grass-forb stage usually follows in the fourth to sixth year. Little rabbitbrush (Chrysothamnus viscidiflorus) resprouts in the first year or two, and shrubs such as sagebrush (Artemisia sp.) and broom snakeweed (Xanthocephalum sarothrae) begin appearing after the sixth year in plant communities in and around the Great Basin, if they are present. In southwestern Colorado, Gambel's oak, serviceberry, true mountain mahogany, and antelope bitterbrush are the dominate shrubs (Erdman, 1970). After 40 years, the shrubs begin to die out and the cover and density of juniper increase dramatically (Barney and Frischknecht, 1974). Barney and Frischknecht (1974) found that Utah juniper begins to bear fruit for the first time at 33 years of age which accounts for the ability of many juniper stands at 40 years of age or older to establish new trees and increase the number of trees per acre dramatically (Erdman, 1970).

Plant succession, according to Erdman (1970), continues in three more stages. The open shrub stage becomes a thicket in about 100 years. As the sere progresses toward climax, the trees begin to overtop the shrubs and gradually suppress the shrubs as the forest matures. After several centuries, the understory is composed mainly of a sparse shrub component, some grass, and several forbs. A climax pinyon-juniper forest develops in about 300 years.

Management Implications

In open stands of pinyon-juniper in the Southwest, fire can be used effectively to kill pinyon and juniper trees less than 4 feet tall. Taller trees are very difficult to kill, even with hot fires, unless a

lot of tumbleweeds have accumulated at the base. Thus, if pinyon and juniper trees are considered a problem in open stands, chaining or dozing would have to precede burning to kill the large trees. Burning should follow chaining or dozing to minimize the ideal microclimate for seedlings.

Reclamation of closed pinyon-juniper stands (no understory of grasses or shrubs) has been tried by several management agencies using various techniques (Jameson et al, 1964; Aro, 1971; Clary, 1971). Of all the methods, prescribed burning, or some combination of burning with other treatments, followed by artificial seeding when necessary is the most effective procedure to reclaim closed stands of pinyon-juniper (Aro, 1971; Springfield, 1976). Burning without any prior treatment must be done on hot days (95 to 100° F) with low relative humidity and 8 to 20 mph winds. These conditions are too hazardous for most land managers (Arnold et al, 1964). Thus, mechanical treatment followed by burning is probably the most acceptable technique to reclaim dense stands of pinyon-juniper even though it is expensive. Burning should be delayed 2 to 3 years after chaining, after most of the pinyon and juniper seeds have germinated (Meagher, 1943).

Production of grasses will increase dramatically following burning and seeding treatments in closed stands of pinyon-juniper. Herbage yields on the Hualapi Indian Reservation in northern Arizona, seeded with crested wheatgrass, western wheatgrass, weeping lovegrass, and yellow sweetclover (Melilotus officinalis), produced 1,660 lb/acre compared to 60 lb/acre for the unburned control (Aro, 1971). On another large scale burning and seeding program in pinyon-juniper woodland, Aro (1971) reported that forage production increased 500 lb/acre of grasses, forbs, and shrubs compared to 223 lb/acre for the control. Where native grasses are present in the understory, reseeding is not necessary (Aro, 1971).

Mixtures of sagebrush and pinyon-juniper can be burned without prior treatment. Generally, thick stands with 45 to 60 percent cover are selected for burning and burned into areas with less shrub cover. Some areas are left to reseed naturally, but aerial seeding is usually considered desirable.

After conversion of pinyon-juniper stands to grassland, reburns should follow about every 20 to 30 years. A definite time is difficult to set because reinvasion of pinyon and juniper is dependent on climate, kind of treatment, initial time span between treatments, intensity of burn, and grazing intensity after the burn. A better guide would be to reburn when the tallest pinyon or juniper tree reaches a height of 4 feet.

State of the Art

More research is needed on prescription techniques to burn closed stands of juniper and mixed stands of sagebrush and pinyon-juniper. We have some information and know generally how to approach burning prescriptions, but we are not comfortable with them. Since closed stands have been burned successfully and economically in northern Arizona without prior treatment, we need to know where this kind of burning can and cannot be done. Can the boundaries be areas with less than 200 trees per acre or areas with less than 600 lb/acre of herbaceous understory? Some reasonably concrete guides are needed.

We have reasonably good baseline data for burning mixed stands of pinyon-juniper and sagebrush with no herbaceous understory. However, we need to know more about setting the boundaries (based on cover and weather) for areas to be burned. Should firelines be prepared via chaining and burning before burning a large block of mixed sagebrush and pinyon-juniper? How wide should the firelines be?

In the open pinyon-juniper grasslands, we know reasonably well what can be done. Here, information as to the minimum amount of fine fuel (herbaceous understory) that is needed to carry a fire would be helpful, although we can estimate that it is 600 to 700 lb/acre.

Our largest void of information on pinyon-juniper communities is the response of the understory species to fire. We have pieces of information, but a number of the shrubs and some cool season grasses deserve more study. Also, alligator juniper needs to be studied in more detail. We need to know how different age classes of this species respond to fire. Our present data indicates that young trees may be more susceptible to fire than the old trees.

Guidelines for reseeding burned pinyon-juniper stands would be helpful. Should drilling be done in preference to aerial seeding when possible? How much of a perennial understory in untreated pinyon-juniper is necessary before artificial reseeding with perennials is not considered necessary?

THE ROLE AND USE OF FIRE IN THE GREAT PLAINS

A STATE OF THE ART REVIEW

Introduction

The prevalence of fire in grasslands historically cannot be denied (Moss, 1932; Sauer, 1944; Stewart, 1951, 1953; Dix, 1960; Humphrey, 1962; Jackson, 1965; Nelson and England, 1971; Kirsch and Kruse, 1972; Seevers et al, 1973). Lightning set many fires (Haley, 1929; Komarek, 1966) and the Indians set some (Heady, 1972), but most of the documented conflagrations of the shortgrass prairie in the late 1880's were due to carelessness by trail outfits, cowboys, and cooks (Haley, 1929). Carelessness by man and dry lightning storms are the major causes of fires in grasslands today. Regardless of their origin, however, fires have always been common and widespread on prairies during drouth years.

Big fires always seem to occur during drouth years that follow 2 or 3 years of above average precipitation and excellent plant growth. Abundant moisture provides abundant fuel for the dry year to follow. When fuels are plentiful and continuous, no matter how a fire starts, it will travel for many miles if the winds are high, relative humidity is low, and air temperatures are high. An example is an account of a fire given by Haley (1929). This fire started in the fall of 1885 in the Arkansas River country of western Kansas. It jumped the Cimarron River, burned across the North Plains of Texas and did not stop until it reached the rugged Canadian River Breaks, a distance of 175 miles. A million acres of the XIT Ranch in Texas alone was burned. Haley (1929) gives several other accounts of large fires (20 by 60 miles) on the High Plains of Texas.

Today many fires still start in grasslands during dry years, but they don't travel as far because more of the prairies are broken up with cultivated land. One of the largest fires that the senior author has seen in the Texas-New Mexico area was started by a broken powerline in Lea County, New Mexico in April 1974. Wind was 55 mph, relative humidity was 5 percent, and air temperature was 100° F. Herbaceous growth from the previous year was abundant. The fire traveled 26 miles, burned 52 sections and crossed three major highways. It stopped when it reached a plowed field. This typifies today's prairie fires and the conditions under which they travel long distances.

Fire History of the Prairie Grasslands

Since prairies do not have trees that can tolerate a series of fires and retain fire scars, this type of historical record for fires in grasslands is not available. The only thing we know for sure is that fires occurred, and explorers and settlers were always concerned about the danger of prairie fires. We can extrapolate some fire frequency data from forests with grassland understories such as ponderosa pine

(*Pinus ponderosa*) forests in the West and pine forests in the Southeast. A variety of sources (Weaver, 1951; Wagner, 1961; Hall, 1976; Arno, 1976; Chapman, 1926; Chapman, 1944) indicate that the fire frequency in pine forests varies from 2 to 25 years. Thus, in the level to rolling topography of prairie grassland it seems reasonable that before the advent of white man a natural fire frequency could have been 5 to 10 years. In rough topography that is dissected with breaks and rivers, such as the Rolling Plains and Edwards Plateau of Texas, fire frequency may have been 20 to 30 years. This latter statement is based largely on historical documents of large mesquite trees in the Rolling Plains by Marcy (1849) and the frequency of fire that would be necessary to keep large Ashe juniper trees (*Juniperus ashei*) out of prairies in the Edwards Plateau.

A question that usually arises is how important have historic fires been in maintaining grasslands? Stewart (1951, 1953) and Sauer (1944) have proposed that treeless grasslands are a product of repeated fires set by aborigines. Wedel (1957) and Hastings and Turner (1966) make a strong case for climate as being the primary factor that characterizes American grasslands; winter rainfall decreases rapidly from the Southeast to the center of the United States and winter snowfall decreases rapidly from the eastern edge of the Rockies to the Southwest and across the northern margin in the Great Plains, making this area unsuitable for tree growth (Wedel, 1957). Wells (1970) shows evidence that the origin and maintenance of grasslands are directly related to topography. He states that the "rougher and more dissected the topography, the greater the former extent and the current spread of woody vegetation at the expense of grasslands."

Based on our experience and knowledge of previous research, climate is the dominant factor that characterizes the North American grasslands, although wide fluctuations in woody vegetation would occur if it were the only factor. The impact of drouth in the maintenance of grasslands has been illustrated by Albertson and Weaver (1945). Following the drouth of the 1930's, they surveyed the mortality of natural trees, timber belts, old shelterbelts, and hedgerows from Oklahoma to Nebraska. Their studies of native trees showed mortality rates ranging from 30 to 93 percent among the deciduous trees (elm, ash, hackberry) and from 35 to 80 percent, or higher, among juniper. On the eastern edge of the Great Plains, "the balance between forest and grassland is so delicate that a little higher water content of soil, a slightly greater humidity, or protection from drying winds throws this balance in favor to tree growth, while the reverse conditions exclude it" (Albertson and Weaver, 1945). Thus, there is good reason to think that climate is the major factor in maintaining grasslands.

Nevertheless, data in the Southern Mixed Prairie indicate that drouth (not necessarily severe), fire, insects, rodents, and competition from grass on level to undulating topography interact as a unit to characterize grasslands. In 1969, we burned 1,200 mesquite trees which

had been previously topkilled by spray in 1966, and killed 26.4 percent of them over a 5 year period (Wright et al, 1967a). We attribute part of the mortality to fire, but over half of it (due to a mild drouth in 1970 and a severe one in 1971) seems to have resulted from the interaction between fire, drouth, insects, rodents, and competition from grass. Thus, a fire every 15 to 30 years in the Southern Mixed Prairie could have a significant effect on the reduction of shrubs.

In general, shrubs and trees have always existed on grasslands. In the Great Plains they are most abundant in the Southern Mixed Prairie, eastern edge of the tallgrass prairie, and rocky breaks or heavily grazed areas where fires are the least frequent. Drouth can control the abundance of shrubs where grass is healthy, but the shifts from grasslands to shrubs and trees may occur on a 100 year cycle if the climate is the only factor. With fire as a factor, as it seems to have been in the past, shrub and tree growth is restricted (Malin, 1953) because fire triggers a significant interaction with other factors.

Southern Great Plains

Distribution, Climate, Soils and Vegetation

The southern Great Plains includes the eastern one-third of New Mexico, the northern two-thirds of Texas and most of Oklahoma. Within this region, the shortgrass prairie (High Plains) lies to the west of the 100° meridian. Precipitation in the shortgrass prairie varies from 15 to 20 inches per year. Soils are primarily clay loams, silt loams, and sandy loams, except for sandy soils in southeastern New Mexico and the Canadian River Country in northern Texas, southeastern New Mexico and western Oklahoma. A caliche layer is frequently present at 20 to 36 inches. Most of the area is tableland that is 4,000 to 6,000 ft (south to north) on the western edge and slopes eastward to 3,000 ft on the edge of the Caprock in Texas. Dominant grasses are buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*) with varying amounts of lesser species such as three-awns (*Aristida* sp.), eragrostis (*Eragrostis* sp.), tridens (*Tridens* sp.), sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*B. curtipendula*), tobosagrass (*Hilaria mutica*), galleta (*H. jamesii*), vine-mesquite (*Panicum obstusum*), bush muhly (*Muhlenbergia porteri*), and Arizona cottontop (*Digitaria californica*). Forbs can be abundant during wet years, but they are seldom a major component of the shortgrass prairie.

Major forbs include annual broomweed (*Xanthocephalum dracunculoides*), false mesquite (*Hoffmanseggia densiflora*), western ragweed (*Ambrosia psilostachya*), horsetail conyza (*Conyza candenis*), warty euphorbia (*Euphorbia spathulata*), silverleaf nightshade (*Solanum elaeagnifolium*), evax (*Evax multicaulis*), woolly plantago (*Plantago purshii*), dozedaisy (*Aphanostephus* sp.), lyreleaf greeneyes (*Berlandiera lyrata*), twoleaf senna (*Cassia roemeriana*), goosefoot (*Chenopodium* sp.), croton (*Croton* sp.), euphorbia (*Euphorbi* sp.), woollywhite (*Hymenopappas* sp.),

sum-mercypress (Kochia scoparia), dotted gayfeather (Liatris punctata), (Machaeranthera sp.), plains blackfoot (Melampodium leucanthus), evening primrose (Denothers sp.), groundcherry (Physalis sp.), white milkwort (Polygala alba), knotweed (Polygonom sp.), hairy paperflower (Psilostrophe villosa), prairie coneflower (Ratibida columnaris), and globemallow (Sphaeralcea sp.).

Dominant shrubs are honey mesquite (Prosopis glandulosa var. glandulosa), shinnery oak (Quercus harvardii), sand sagebrush (Artemisia filifolia), perennial broomweed (Xanthocephalum sarothrae), yucca (Yucca sp.), and fourwing saltbush (Atriplex canescens). Occasional shrubs of other species include winterfat (Eurotia lanata), skunkbush (Rus trilobata), acacia (Acacia sp.), elbowbush (Foresteria pubescens), and dalea (Dalea sp.). Cactus species can also be abundant. The most prevalent species include plains prinklypear (Opuntia polyacantha), brownspine pricklypear (O. phaecantha), cholla (O. imbricata), and tasajillo (O. leptocaulis).

East of the shortgrass plains lies the mixed prairie (Rolling Plains and Edwards Plateau). It includes most of west-central Texas and eastern Oklahoma, except for the Panhandle of Oklahoma. Elevation drops from 3,000 ft along the western edge to about 900 ft along the eastern edge in central Texas and Oklahoma. Topography undulates with occasional breaks and rivers. Width of this zone is about 150 miles and precipitation varies from 20 inches on the western edge to 28 inches on the eastern edge. Soil textures are primarily clay loams, silt loams, and sandy loams.

Honey mesquite and Ashe juniper (Juniperus ashei) dominate the overstory in Texas, but these species are not very prevalent in Oklahoma. In the Rolling Plains, where honey mesquite dominates the overstory, lotebush (Zizphus obtusifolia) is an important subdominant shrub that is used for cover by quail and for nesting by many songbirds (Renwald et al, 1978). Other shrubs present include fourwing saltbush, elbowbush, ephedra (Ephedra sp.), skunkbush, dalea, and acacia. However, breaks throughout the Rolling Plains contain large amounts of the sprouting redberry juniper (Juniperus pinchota). Cactus species similar to those for the shortgrass prairie are also present throughout the Rolling Plains.

Dominant grasses include sideoats grama, tobosagrass, buffalograss, little bluestem (Schizachyrium scoparium), and Texas wintergrass (Stipa leucotrica). Other grasses that are often present include vine-mesquite, Arizona cottontop, sand dropseed, white tridens (Tridens albescens), three-awn species, plains bristle-grass (Setaria leucopila), and green sprangletop (Leptochloa dubia). Many annual forbs can be present following wet winters, but annual broomweed and bitterweed (Hymenoxys odorata) are the only forbs that are very abundant over a wide area. Other species include Engelmannia sp., Gaillardia sp., Oenothera sp., Aphanostephus sp., Asclepias sp., Astragalus sp., Chenopodium sp.,

Croton sp., Euphorbia sp., Gaura sp., Grindelia sp., Helianthus sp., Hymenoxys sp., Kochia sp., Liatris sp., Physalis sp., Plantago sp., Polygala sp., Prionopsis sp., Psoralea sp., Ratibida sp., Solanum sp., Sphaeralcea sp., Teucrium sp., Thelosperma sp., Vernonia sp., and Zinnia sp.

In the Edwards Plateau southeast of the Rolling Plains, Ashe juniper dominates the overstory, but many other shrubs and trees are present. Major species include interior live oak (Quercus virginiana), Texas oak (Q. shumardii var. texana), post oak, blackjack oak,. smoothleaf sumac (Rhus glabra), Mexican redbud (Cercis canadensis var. mexicana), and shin oak (Quercus sp.). Dominant grasses include little bluestem, sideoats grama, Texas wintergrass, tall grama (Bouteloua pectinata), vine-mesquite, buffalograss, and meadow dropseed (Sporobolus asper var. hookeri). Forbs are similar to those in the Rolling Plains.

From central Texas and Oklahoma to the eastern edges of these states, tall grasses are mixed with various amounts of the Cross Timbers, which is dominated by post oak (Quercus stellata) and blackjack oak (Q. marilandica) on sandy soil. Precipitation varies from 27 to 40-45 inches. Deep sandy loam and silt loam soils slope generally to the east. Dominant grasses are little bluestem, big bluestem (Andropogon gerardi), Indiangrass (Sorghastrum nutans), switchgrass (Panicum virgatum) and eastern gramagrass (Tripsacum dactyloides). Shrubs vary in their abundance, but smoothleaf sumac, leadplant (Amorpha canescens), and Prunus sp. are important species. Forbs are similar to those mentioned for the tallgrass prairie of the Central Great Plains in the following section.

Fire Effects - Shortgrass Prairie Grasses

Grasses

During dry years, most species of the shortgrass prairie are harmed by fire. Following a spring wildfire, when the soil was dry, Launchbaugh (1964) found that the recovery time for a buffalograss (Buchloe dactyloides) and blue grama (Bouteloua gracilis) mixture took three growing seasons. The mixture recovered 35, 62, and 97 percent following the first, second, and third growing seasons. Hopkins et al (1948) reported similar results in west-central Kansas. Western wheatgrass recovered more slowly--18, 27, and 77 percent for the three growing seasons (Launchbaugh, 1964). Following another wildfire in New Mexico with less moisture stress, Dwyer and Pieper (1967) found that the production of blue grama was reduced 30 percent the first year. With above average precipitation the second year after burning, blue grama was 97 percent recovered. Prescribed burns in Texas during years with above normal winter and spring precipitation show that buffalograss and blue grama can tolerate fire very well with no loss in herbage yield at the end of the first growing season (Trlica and Schuster, 1969; Heirman and Wright, 1973; Wright, 1974) (Table 1).

Table 1. Yields (lb/acre) of Buffalograss and Blue Grama After Burning During a Series of Dry Years and a Series of Wet Years.

	Burned		Unburned	
Year After Burn	Current Growth	Litter	Current Growth	Litter
Wet years (Texas data)				
Buffalograss				
First (1968)	1,686		1,494	728
Second (1969)	2,063	306	1,928	458
Third (1970)	1,398	1,572	1,330	906
Bluegrama				
First (1970)	1,680		1,429	2,474
Second (1971)	1,369	699	1,247	2,584
Third (1972)	2,142	1,750	1,754	1,932
Dry years (Kansas data)1/				
Buffalograss-Blue grama				
First (1959)	1,100		3,150	500
Second (1960)	1,840	250	3,000	500
Third (1961)	2,600	330	2,650	550

1/ Taken from Launchbaugh, 1964.

The tolerance of most grass species to fire in the shortgrass prairie under different moisture regimes seems to be similar to that for buffalograss and blue grama. Red three-awn (Aristida longiseta) and sand dropseed (Sporobolus cryptandrus) are generally harmed by fire (Hopkins et al, 1948; Dwyer and Pieper, 1967; Trlica and Schuster, 1969). By contrast, Wright (1974) found that sand dropseed tolerated fire very well when winter and spring precipitation was 40 percent above normal. Other species that Dwyer and Pieper found to be harmed by fire included slim-stemmed muhly (Muhlenbergia filiculmis), ring muhly (M. torreyi), wolf-tail (Lycurus phleoides), and Galleta (Hilaria jamesii). However, this latter data is based on a wildfire during a year when precipitation was below average. Tumble windmill grass (Schedonnardus paniculatus) was not harmed by fire (Trlica and Schuster, 1969). Weeping lovegrass (Eragrostis curvula), an introduced species, is increased 14 percent by burning, but the biggest benefit from fires is a 53 percent increase in utilization (Klett et al, 1971).

In the southern shortgrass plains, sandy lands are common among the heavy clay soils that are dominated by sand bluestem (Andropogon hallii), little bluestem (Schizzchyrium scoparium), switchgrass (Panicum virgatum) and shinnery oak (Quercus havardii). Burning generally increases production of sand bluestem and switchgrass about 300 lb/acre and similarly decreases production of little bluestem with a net increase in total forage of 20 percent (McIlvain and Armstrong, 1968).

Forbs

Grasses provide the major portion of prairie vegetation, but frequently forbs occur in endless numbers of species and individuals, particularly during wet years. Heirman and Wright (1973) found that spring burning was detrimental to many forms: annual broomweed (Xanthocephalum dracunloides), silverleaf nightshade (Solanum elaeagnifolium), western ragweed (Ambrosia psilostachya), and horsetail (Conyza canadensis). Warty euphorbia (Euphorbia spathulata), rabbit's tobacco (Evax multicaulis), and woolly plantago (Plantago purshii) were not affected, and false mesquite (Hoffmanseggia densiflora) was favored by spring burning.

Total forb yields are usually decreased more by spring burns than fall burns (Hopkins et al, 1948). In all cases, however, forb composition will be altered the least by burning when plants are dormant. Young, active growing forbs will be severely harmed by fire.

Shrubs

The shortgrass prairie does not have many shrubs except in the southern mixed prairie where shrubby mesquite is present on native ranges today. However, mesquite has not always been as prevalent a shrub on the High Plains of Texas as it is currently. In the journals of Captain R. B. Marcy (1849) when he and his command traveled over the

northern part of the Llano Estacado near Amarillo, Texas he gives the following description of what he saw:

> "When we were on the high tableland, a view presented itself as boundless as the ocean. Not a tree, shrub, or any other object, either animate or inanimate, relieved the dreary monotony of the prospect; it was a vast, illimitable expanse of desert prairie--the dreaded 'Llano Estacada' of New Mexico; or, in other words, the great Sahara of North America. It is a region almost as vast and trackless as the ocean--a land where no man, either savage or civilized, permanently abides; it spreads forth into a treeless, desolate waste of uninhabited solitude, which always has been, and must continue, uninhabited forever; even the savages dare not venture to cross it except at two or three places, where they know water can be found. The only herbage upon these barren plains is a very short buffalograss, and, on account of a scarcity of water, all animals appear to shun it."

Today, honey mesquite is prevalent on the High Plains and it is almost impossible to kill it with fire (Wright et al, 1976). Even the seedlings are very tolerant to fire (Fisher, 1947). Moreover, honey mesquite on the High Plains has exceptional ability to resprout, compared to mesquite in the Rolling Plains. With this background and very few observations of honey mesquite by early explorers on the High Plains (Malin, 1953; Box, 1967), we are of the opinion that, before white man's arrival, honey mesquite had a high frequency and low cover on the High Plains. Also, because of the necessity to survive frequent fires in its past history, honey mesquite seems to be genetically adapted to fire and has vigorous sprouting ability. In a low state of growth with frequent fires it would seem that the combination of fire, drouth, competition from grasses, and damage from rodents, particularly rabbits and rats, would have a serious effect on honey mesquite and keep it at a low height.

On sandy lands in eastern New Mexico, northern Texas and western Oklahoma, shinnery oak (Quercus havardii) is abundant, although in southeastern New Mexico the sandy land is dominated by shrubby honey mesquite. Shinnery is very fire tolerant and the density of its stems increases 15 percent after burning (McIlvain and Armstrong, 1966). However, no acorns are formed during the year of a burn, which could affect prairie chicken and turkey populations.

In New Mexico, algerita, fourwing saltbush, winterfat (Eurotia lanata), and skunkbush sumac (Rhus trilobata) resprout vigorously after fire (Dwyer and Pieper, 1967). Chickasaw plum (Prunus angustifolia) and aromatic sumac (Rhus aromatica) sprout vigorously after burning in the southern Great Plains (Jackson, 1965). In the northern Panhandle of Texas, sand sage (Artemisia filifolia) is a nonsprouter but comes back vigorously as a seedling after fire (Jackson, 1965).

Cacti seem to be quite easily killed by fire, at least over a 2 year period. Tasajillo (Opuntia leptocaulis) is easily killed by fire with 80 percent mortality (Bunting and Wright, 1978). Cholla (O. imbricata) and pricklypear (O. phaeacantha) are also easily killed by fire if they are less than 1 ft high. In New Mexico, Dwyer and Pieper (1967) found that chollas less than 1 ft high were reduced by 50 percent after burning, but cacti over 1 ft were hardly damaged. Heirman and Wright (1973) reported similar data for West Texas. This is largely because the flames in a shortgrass community are usually from 1-1/2 to 2 ft high and will engulf plants easily that are less than 1 ft high. Plants which are taller are not burned at the higher levels and thus they survive fire quite easily in the shortgrass prairie. Chaining the tall cholla plants before burning will greatly increase their mortality (Heirman and Wright, 1973).

Fire Effects - Mixed Prairie

Grasses

Most grasses of the mixed prairie tolerate fire well during normal to wet years, but sideoats grama (Bouteloua curtipendula) and Texas wintergrass (Stipa leucotrica) can be severely harmed. Sideoats grama, the rhizomatous form, is almost always reduced 40 to 50 percent by fire and requires 3 years for full recovery (Hopkins et al, 1948; Wright, 1974). During exceptionally wet years it tolerates fire reasonably well with only a 12 percent reduction in yield (Wink and Wright, 1973). Texas wintergrass is severely harmed by sweeping broadcast fires (Dahl and Goen, 1973), but increases following creeping, cool fires (Bean et al, 1975). Little bluestem (Schizachyrium scoparium) will decrease as much as 58 percent during dry years (Hopkins et al, 1948) or increase as much as 81 percent during wet years (Wink and Wright, 1973).

Tobosagrass (Hilaria mutica) is a southern desert species that is quite prevalent on bottomland sites in the southern mixed prairie. It is a highly productive species (Paulsen and Ares, 1962; Dwyer, 1972) until it accumulates large amounts of litter (Wright, 1969) that decays slowly (Weaver and Albertson, 1956). Young tobosagrass leaves are palatable, but as plants mature and accumulate litter, they become coarse and unpalatable (Herbel and Nelson, 1966; Wright, 1972; Heirman and Wright, 1973).

Burning can greatly increase the production and palatability of tobosagrass during normal to wet years (Heirman and Wright, 1973). During wet years after burning, tobosagrass will increase over 2,000 lb/acre. Over a series of dry, normal, and wet years (5 years), tobosagrass production increased an average of 1,030 lb/acre the first growing season following a burn (Wright, 1972). Total equilibrium during the fourth year after burning (Wright, 1972; Neuenschwander,

1976). However, in southern New Mexico where annual precipitation is only 9 inches per year, no increase in tobosagrass yields can be expected after burning (Dwyer, 1972).

Since tobosagrass is such a coarse grass, it should be grazed within a few weeks after burning. If it is rested for 3 or 4 months, as we do for most other grasses, it will be so coarse that animals will not eat it. Cattle normally like to eat this grass during the spring and fall periods when it is growing rapidly. Wright and Heirman (1973) found that tobosagrass utilization could be increased many-fold following a burn. Normally cattle eat only about 10 percent of tobosagrass but following a burn they will eat as much as 66 percent of the tobosagrass (Heirman and Wright, 1973).

Since tobosagrass and buffalograss often grow in combination and cattle will eat tobosagrass in preference to buffalograss (Heirman and Wright, 1973), burning followed by grazing can be a means to increase the vigor of desirable grasses and in general improve the condition of the range. However, tobosagrass cannot take very heavy utilization for an extended number of years (Canfield, 1939). Fifty percent should probably be the maximum utilization of tobosagrass during any year.

As long as moisture is adequate, vine-mesquite (Panicum obtusum), Arizona cottontop (Digitaria californica), plains bristlegrass (Setaria leucopila), Texas cupgrass (Eriochloa sericia), and meadow dropseed (Sporobolus asper var. hookeri) thrive after fire (Box et al, 1967; Wink and Wright, 1973; Wright, 1974). Tall grama (Bouteloua pectinata) also does well after burning for 2 years, whereas Arizona cottontop will show increased yields after burning for only 1 year (Wright, 1974). The bunchgrass form of sideoats grama also seems to thrive after fire (Wright, 1974).

Cool season annual grasses are severely harmed by spring burning. In the southern mixed prairie this affects primarily little barley (Hordeum pusillum) and Carolina canary grass (Phalaris caroliniana). Where these species are the only cool season grasses growing during the winter, care should be taken not to burn an entire pasture. Otherwise, there is very little green feed for animals during the winter and early spring months.

Forbs

Forbs which begin growing prior to the burning season are usually harmed by fire, and those that initiate growth after the burning season are usually not harmed by fire. In the southern mixed prairie, the species that are usually harmed during the first growing season after burning include annual broomweed, mare's tail, plains dozedaisy (Aphanostephus ramosissimus), scarlet globemallow, and bitterweed. Species which are common on burns include lambsquarter (Chenopodium leptophyllum), silverleaf nightshade (Solanum elaeagnifolium),

porcupinegrass (Stipa spartea var. curtiseta). Other species present are Pennsylvania sedge (Carex pennsylvanica), Carex eleocharis, prairie dropseed, red three-awn, sand bluestem, big bluestem, prairie sandreed, and sleepygrass (Stipa robusta). A variety of forbs can occur. Major forb species include Astragalus sp., heath aster, aromatic aster (A. oblongifolius), Missouri goldenrod, woolly plantain, Penstemon sp., few-flowered psoralea, hairy golden-aster (Chrysopsis villosa), Phlox sp., little club moss, wild lettuce (Lactuca pulchella), western yarrow (Achillea millefolium), plains erysimum (Erysimum capitatum), scarlet gaura (Gaura coccinea), white milkwort (Polygala alba), herbaceous sage (Artemisia glauca), and dotted gayfeather. Dominant invaders include summer cypress (Kochia scoparia), yellow sweetclover (Melilotus officinalis), gumweed (Grindelia squarrosa), foxtail barley (Hordeum jubatum), and cheatgrass (Bromus tectorum). A number of shrubs are present, which include fringed sagebrush, western snowberry, russet buffaloberry (Sheperdia canadensis), rose, Nuttall's saltbush (Atriplex nuttallii), herbaceous sage, plains pricklypear, yucca (Yucca glauca), perennial broomweed, fourwing saltbush, lead plant, willow, and wild plum (Prunus besseyi).

Tallgrasses occupy the eastern edges of North Dakota and South Dakota and the western edge of Minnesota. Surface soil textures are primarily loam, silt loam, and silty clay loam. Elevation varies from 800 to 1,800 ft, and topography varies from a level to gently rolling glacial plain. Precipitation varies from 19 inches in northeastern North Dakota to 30 inches in south-central Minnesota. Grasses are very similar to those mentioned for the tallgrass prairie in the Central Great Plains with a few exceptions. Cool season grasses, such as porcupinegrass, bearded wheatgrass, quackgrass (A. repens), slender wheatgrass (A. trachycaulum), smooth brome (Bromus inermis), and Kentucky bluegrass (Poa pratensis), are more abundant as codominants with the bluestems, switchgrass, prairie cordgrass, and Indiangrass. Note that quackgrass, smooth brome, and Kentucky bluegrass are introduced species. The shrubs, silverberry (Elaeagnus argentea) and fringed sagebrush, can be added to western snowberry, prairie rose, and smoothleaf sumac. Forbs are very similar to those mentioned for the Central Great Plains. Much of Minnesota is a mixture of grassland and forests, but the grassland species are very similar to those already mentioned for the tallgrass prairie.

Fire Effects - Mixed Prairie

The only fire research that has been done in the mixed prairie of the northern Great Plains is that of Dix (1960) in western North Dakota, and of Gartner and Thompson (1972) in the forest-grass ecotone of the Black Hills. Dix (1960) found that a spring burn reduced herbage yields about 50 percent after one growing season, but that total yields had fully recovered within 4 years after a later fall burn. A late summer burn (August) was not quite fully recovered after 5 years. With a predominance of cool season grasses, a slower recovery than

that for warm season grasses could easily be anticipated based on research for cool season grasses in the sagebrush-grass region (Wright and Britton, 1976).

Dix (1960) found that spring burning reduced the frequency of bearded wheatgrass, blue grama, prairie sandreed, needle-and-thread, and green needlegrass. For western wheatgrass, Carex eleocharis, threadleaf sedge, Pennsylvania sedge, junegrass, and muhlenbergia, the frequency remained the same or higher. However, this does not mean that herbage yield wasn't reduced for several years as it very well might have been. Fringed sage, Arkansas rose, and silverleaf psoralea had significantly reduced frequencies, whereas most forbs remained unchanged.

The longer term data (4 years) following a fall burn showed relatively few changes in composition except for a possible reduction in threadleaf sedge, fringed sagebrush, leafy spurge (Euphorbia esula), and little club moss. Hemeoma hispida, stickseed (Lappula redowski), and herbaceous sage increased. The late summer fire also showed that Pennsylvania sedge, prairie sandreed, hairy golden aster (Chrysopsis villosa), and wild lettuce had been harmed by fire but no explanation was given. Possibly, this was still a very active growing season for these species.

This research indicates that there are no benefits to be derived by burning the herbaceous species in the mixed prairie of the northern Great Plains where cool season grasses dominate. On the other hand, fire is capable of killing silver sagebrush (Artemisia cana) (Rowe, 1969), fringed sagebrush, and little club moss (Dix, 1960). However, to get rid of the shrubs, a manager will have to allow 3 to 5 years for full recovery of the range. This may be a high price to pay for control of shrubs except in very special situations.

In the forest-grass ecotone of the Black Hills, Gartner and Thompson (1972) did not give plant yield data after burning, but species composition (percent by weight) did not differ significantly between the burned and unburned pasture. Little bluestem and big bluestem made up 82 to 85 percent of the total forage yield. Based on research from other areas, these species are probably not harmed by fire and could easily be burned during years with normal to above normal precipitation to control scrubby ponderosa pine trees or undesirable shrubs.

Fire Effects - True Prairie

One of the most classic stories about the effect of fire on tall-grass prairie is the Curtis Prairie in Wisconsin which was rejuvenated with fire (Curtis and Partch, 1948; Anderson, 1972). This particular area was abandoned from cultivation in 1932. By 1936, the principal perennials were quackgrass, Kentucky bluegrass, and Canada bluegrass (Poa compressa) (Curtis and Partch, 1948). Various annuals were also present. A number of prairie forbs and grasses were transplanted into

the area in 1936 and 1937 at a density of 2.6 plants per 100 ft^2. It was soon evident that the species were not spreading or holding their own against the bluegrass sod, so fire was introduced experimentally to test the desirability of burning and to determine the best season and frequency of burning. Since 1950, one-third to two-thirds of the 20-acre prairie has been burned every year.

Annual burning between 1941 and 1946 reduced bluegrass sod 80 percent and permitted big bluestem, rattlesnake master (Eryngium yuccifolium), goldenrod (Solidago rigida), tall gayfeather (Liatris aspera), ragweed (Ambrosia artemisiifolia), white heath aster, and erigeron (Erigeron annua) to increase. Atlantic wild indigo (Baptisia leucantha) showed no effect from fire, and purple coneflower (Echinacia purpurea) was the only species reduced by fire. A more recent composition of the prairie from Cottam and Wilson (1966) is shown in Table 3. Note the increases in big bluestem, little bluestem, Indiangrass, Solidago sp., Eryngium sp., Lactuca sp., tall gayfeather, Ratibida sp., and Silphium sp. Quackgrass and Kentucky bluegrass were still declining as of 1961. Wild parsnip (Pastinaca sativa), a troublesome weedy species, is also declining (Anderson, 1972).

In eastern North Dakota, Hadley (1970) also showed an increase in big bluestem and little bluestem, and a decrease in Kentucky bluegrass following spring burning, as did Anderson (1972). Other species that increased were prairie dropseed, prairie cordgrass, saltgrass (Distichlis stricta), western snowberry, and Arkansas rose. Wheatgrasses increased on upland sites but declined on lowland sites. Those species that declined were porcupinegrass, needle-and-thread, Poa sp., Muhlenbergia sp., foxtail barley, prairie clover, and heath aster. All of this data was based on yields taken in 1966, a drier than normal year (Hadley, 1970). Total herbage yield was 2,980 lb/acre on the unburned plot and 3,833 lb/acre on the burned plot.

Total production of herbage on the Curtis Prairie in Wisconsin 1 year after burning was 8,478 lb/acre compared to 4,180 on the unburned site (Anderson, 1972). Similar differences for the same prairie have been shown by Peet et ál (1975). Removal of litter, increased soil temperatures, and light in early spring were the main factors attributed to the increased plant growth (Peet et al, 1975).

In eastern South Dakota, Kirsch and Kruse (1972) have conducted various burns to improve wildlife habitat. One year after burning, the increasers (based on plant cover) were big bluestem, little bluestem, prairie sandreed, blue grama, Leiberg panicum (Panicum leibergii), needle-and-thread, porcupinegrass, and needlegrass. Slender wheatgrass, smooth brome (Bromus inermis), and prairie cordgrass decreased. Grasses remaining unchanged were quackgrass, bearded wheatgrass, junegrass, and Kentucky bluegrass. Most forbs increased or remained unchanged. Only Canada thistle (Cirsium canadensis) and rushes (Juncas sp.) declined. Cover of shrubs and half-shrubs remained unchanged.

Table 3. Frequency of Plant Species in Curtis Prairie, Stand A, 1951 and 1961.[1/]

	Frequency 1951	Frequency 1961
Prairie Species		
Achillea millefolium	44	55
Ambrosia artemisiifolia	79	53
Andropogon gerardi	6	44
Andropogon scoparius	--	47
Aslepias verticillata	59	61
Eryngium yuccifolium	1	69
Helianthus grosseseratus	--	5
Lactuca canadensis	48	84
Liatris aspera	2	37
Monarda fistulosa	53	73
Ratibida pinnata	6	32
Rudbeckia hirta	--	3
Silphium terebenthinacium	2	21
Solidago gigantea	--	3
Solidago nemoralis	--	81
Solidago rigida	--	8
Sorghastrum nutans	--	68
Other Species		
Agrostis alba	--	8
Aster pilosus	71	31
Pastinaca sativa	32	11
Poa compressa	79	97
Solidago altissima	32	48
Weeds		
Agropyron repens	29	11
Oxalis stricta	54	44
Poa pratensis	60	13
Trifolium repens	74	43

1/ Data of Cottam and Wilson 1966.

Vogl (1967) found scrub oak (Quercus ellipoidalis) very abundant in Wisconsin prairies that had been protected from fire for 25 to 80 years.

Canadian Great Plains

The Great Plains extend about 250 miles into southeastern Alberta, southern Saskatchewan, and the southern tip of Manitoba. Except for the eastern edge, it is mixed prairie and bounded on the north by aspen (Populus tremuloides) parkland, which varies in width (north to south) from 50 to 175 miles. Topography is gently rolling to level and varies in elevation from 3,500 ft in south-central Alberta down to 800 ft in southern Manitoba. Precipitation varies from 10 to 20 inches, increasing as you go northward or eastward. Soil textures are loam, silt loam, and silty clay loam.

Changes in vegetation vary primarily from north to south as you go from the Brown soil zone through the Dark Brown soil zone to the Black soil zone (Rowe, 1972; Nester and Peters, 1977). The Brown and Dark Brown soil zones contain the same grasses as mentioned for the mixed prairie in eastern Montana except for the addition of western porcupinegrass and rough fescue in the Dark Brown soil zone. Shrubs are primarily western snowberry, fringed sagebrush, winterfat, Nuttall's saltbush, rose, and silverberry. Forbs are not very abundant, but prairie phlox (Phlox hoodii) and little club moss are the most common.

The aspen parkland is a mosaic of aspen and mixed prairie. The dominant grass is rough fescue.

Fire Effects

In the mixed prairie of southern Alberta, spring burning reduced forage production by 90 percent the first year and 15 percent the second year, with recovery completed by the third year (Clarke et al, 1943). The reduction in yields following burning were greater on vegetation of the "Agropyron-type" than on communities dominated by blue grama and needle-and-thread (Stipa comata). Effects of fall burning were less obvious. Production was reduced by 30 percent the first year, with recovery complete by the end of the second year.

Bailey and Anderson (1978) found that the effect of fire on a rough fescue-western porcupinegrass community is complex and cannot be considered simply detrimental or beneficial. Total herbage yields following spring or fall burns remained the same as the unburned control (1,050 to 1,215 lb/acre). However, there were significant changes in plant composition.

Following spring burning, Bailey and Anderson (1978) found a reduction in plant cover for rough fescue, hooker's oatgrass (Helietotrichon hookeri), and sedge (Carex sp.), but no change in cover for western porcupinegrass, slender wheatgrass, or bearded wheatgrass. It

took 3 years for rough fescue to recover. Parry oatgrass (Danthonia parryi) and timothy (Phleum pratense) are also harmed by spring fires (Bailey, 1978). Perennial forbs more than doubled, particularly milk vetch (Astragalus sp.), three-flowered avens (Geum triflorum), western yarrow, and blue bur (Lappula redowski). In another study by Anderson and Bailey (1978), they found that vetch (Vicia and Lathyrus sp.), woundwort (Stachys palustius var. pilosa), and bedstraw also increased 1 year after burning. Following fall burning, Bailey and Anderson (1978) found that fire was less damaging to rough fescue but somewhat harmful to western porcupinegrass. Hooker's oatgrass was severely harmed, as well as both wheatgrasses. Forbs responded to fall burning similarly as they did to spring burning.

Shrubs responded the same to fire whether they were burned in the spring or fall (Bailey and Anderson, 1978). Silverberry and fringed sagebrush were seriously harmed. Rose and western snowberry were moderately harmed (Anderson and Bailey, 1978; Bailey and Anderson, 1978). Herbaceous sage and raspberry (Rubus strigosus) increased dramatically.

Annual early spring burning in one area of central Alberta has been conducted over the past 25 to 30 years (Bailey, 1978). Preliminary results show that the percent frequency of all shrubs--silverberry, rose, aspen, serviceberry, and chokecherry--is higher on the burned than unburned plots. Frequency of western snowberry remained the same and only Rosa acicularis decreased. However, cover of all shrubs, except for herbaceous sage, was reduced 83 percent by annual burning. The high frequency but low cover of shrubs seems to be indicative of a fire environment for tenacious shrubs.

Grasses and forbs that increased under the long-term burning program included prairie sandreed, sedge (Carex obtusata, C. heliophila), Missouri goldenrod, bushpea (Thermopsis rhombifolia), western yarrow, and bedstraw. Rough fescue and western porcupinegrass decreased.

Based on what is presently known, fire has potential in the grasslands of Canada to remove litter buildups on ungrazed fescue grassland and to control shrubs with only moderate damage to the grasses. Forage losses can be minimized by using fire only during those springs that are preceded by above normal precipitation. The desired interval for use of fire to control shrubs is probably 5 to 10 years. More use of these ranges by sheep and game in combination with burning may enhance the healthiness of these grasslands.

Beneficial Effects of Fire in Prairie Grasslands

Where it is applicable, the major benefits of prescribed fire in grasslands are control or undesirable shrubs, increased herbage yields, increased utilization of coarse grasses, increased availability of forage, improved wildlife habitat (more food with unburned patches for cover), and control of cool season species where warm season grasses

are dominant (Wright, 1974). Several of these objectives can be achieved simultaneously with one burn, which is the advantage of using fire as a management tool.

When large amounts of litter accumulate in a grassland and cause plant growth to stagnate, fire is a very effective tool in the tallgrass and southern mixed prairie grasslands to reduce litter and raise soil temperatures and increase plant growth (Weaver and Rowland, 1952; Kucera and Ehrenreich, 1962; Peet et al, 1975; Sharrow and Wright, 1977). Removal of the litter permits soil temperatures to rise 10 to 30° F in early spring (Peet et al, 1975), which stimulates nitrification by bacteria (Sharrow and Wright, 1977). The high populations of bacteria after fire (Neuenschwander, 1976) break down organic matter in the soil, produce additional nitrates, and this sequence of events along with optimum growing temperatures created by the bare soil when moisture is adequate allow warm season plants to grow at an optimum rate (Sharrow and Wright, 1977). Thus, most of the fertilizing effect from fire in grasslands comes from nitrates that are released following the consumption of organic matter by bacteria after the fire, not the addition of nutrients in ash (Old, 1969; Sharrow and Wright, 1977).

The young, tender growth after fire is naturally more palatable and easily accessible to livestock and wildlife. This enables us to use fires as a very effective tool to attract livestock to grasses that are normally too coarse and contain too much litter to be palatable. Undesirable cool season grasses and forbs can be reduced with spring burns. Forbs that provide an important food source for many upland game birds are frequently more easily available on burned areas. Resprouts of shrubs are not only more accessible but may be more nutritious up to 3 years after the burn.

Controlling shrubs in the southern mixed prairie, tallgrass prairie, and aspen parkland is a major objective that can be achieved by the use of fire. In Texas we have shown that fire can be used to topkill mesquite, completely kill 25 percent of the mesquite on upland sites, kill 50 to 80 percent of all cactus species, and kill Ashe juniper (Britton and Wright, 1971; Wink and Wright, 1973; Wright et al, 1976; Bunting and Wright, 1978). Bragg and Hulbert (1976) have shown conclusive evidence that the tallgrass prairie is easily invaded by shrubs and trees without fire. Preliminary findings on an area burned for 30 consecutive years in Alberta, Canada indicate the fire can be used to reduce cover of shrubs (Bailey, 1978).

In the shortgrass prairie and northern mixed prairie, fire does not appear to have any major benefits, except for the few special situations noted in this paper.

Potential Impact of Fire in Prairie Grasslands

Detrimental effects of fire are generally associated with its misapplication. For example, if we burn during drouth years, we will seriously harm the desirable herbaceous species and have less than normal herbage yields for at least 2 years. This is especially true in the shortgrass and mixed prairies. As one moves to the northern Great Plains, more cool season species such as *Stipa* sp. and *Agropyron* sp. are encountered and these species may be harmed for 2 to 5 years, depending on when they are burned.

Nevertheless, dry years are often best for long-term effectiveness in killing some shrubs when amounts of fine fuel are minimal. Juniper species are a good example. In these cases fire may be needed only every 20 to 30 years and burning during drouths can be tolerated if the pastures can be rested until the herbaceous species are fully recovered.

Erosion following fires is not likely to be a serious problem unless the slopes are over 20 percent (Wright et al, 1976) or the soils are sandy. Sandy soils blow easily after being burned. If burning is considered desirable on such soils, low intensity fires should probably be used so that some of the area would remain unburned and a mosaic of burned-unburned areas results.

Improper smoke management can have serious impacts on populated areas. Burning should be done when we have a steep adiabatic lapse rate (day time) and the smoke will rise and disperse at high altitudes. Winds should always be blowing away from nearby towns. Night-time burning is particularly undesirable because the smoke will drift and settle in low-lying valleys and stay there until the middle of the next day. This can lead to complaints to pollution boards and further restrictions on burning. We should avoid such incidents by burning within a state's prescribed burning regulations and get the area burned in as short a time as possible. Most people are very tolerant of smoke for a few hours, but not for several days.

Frequency of fire can also be a problem. It appears that we should not use fire more frequently than every 5 to 10 years in the western and central portion of the Great Plains. Long-term declines in production of grasses resulting from too frequent burning have been documented (unpublished research by Wright and Bailey). As one goes eastward where the precipitation increases, fire frequency may be every 1 to 3 years without harming the grasses (Anderson et al, 1970).

Management Implications

Shortgrass Prairie

Few uses can be found for fire in the shortgrass prairie. First of all, the grasses do not benefit from fire. They tolerate fire with

no loss in forage during wet years (Trlica and Schuster, 1969; Heirman and Wright, 1973; Wright, 1974), but are moderately to severely harmed for 2 to 3 years when precipitation is below normal (Hopkins et al, 1948; Launchbaugh, 1964; Dwyer and Pieper, 1967). Nevertheless, prescribed burns can be used to clean up chained debris and kill pricklypear and other Opuntia species less than 1-1/2 feet tall (Heirman and Wright, 1973). In eastern New Mexico, prescribed fires can be used to control small juniper trees (Dwyer and Pieper, 1967). Fire also can be used on sand shinnery oak ranges that are in good condition to increase herbage production (McIlvain and Armstrong, 1968).

Mixed Prairie

Central and Southern Great Plains

Prescribed fire has a wide variety of uses in the mixed prairie. It is especially useful in the southern and central mixed prairie to increase production and palatability of coarse grasses, such as tobosagrass and little bluestem, that have a tendency to accumulate litter. Most grasses tolerate fire well during normal to wet years, except for sideoats grama and Texas wintergrass (Wright, 1974). Cool season annuals such as little barley and Carolina canarygrass are severely harmed. Spring fires also kill many undesirable forbs, e.g., annual broomweed, and cool season annuals, which minimizes competition for the warm season perennials. Thus, if soil moisture is adequate, the warmer soil and increased nitrates with reduced competition from "weeds" provide an ideal environment for growth of warm season grasses. Fire can be used in the southern mixed prairie on a 5 to 8 year frequency (Sharrow and Wright, 1977).

Fire is also effective for burning down dead honey mesquite stems (Britton and Wright, 1971) and killing some honey mesquite trees (Wright et al, 1976). Green honey mesquite trees are difficult to kill. Young honey mesquite trees, up to 1.5 years of age, that were burned at temperatures from 260 to 600° C, were easily killed by fire, severely harmed at 2.5 years of age, and very tolerant of fire after 3.5 years of age (Wright et al, 1976).

Other uses for fire in the mixed prairie are to kill 50 to 80 percent cactus (Opuntia sp.) (Bunting and Wright, 1978), clean up chained debris (Wright, 1972), remove dead piles of Ashe juniper and kill young Ashe juniper trees (Wink and Wright, 1973), remove brush to ease handling of livestock and, in some cases, improve wildlife habitat.

Generally, pastures should be burned on a manageable unit basis, except when tobosagrass is dominant. About one-fifth to one-eighth of each tobosagrass pasture should be burned each year (burn new areas on a rotational basis within each pasture), and the cattle need to be on the burn within 2 to 3 weeks after the fire. They graze this species in the spring and fall, which takes pressure off the other grasses.

Animals will not graze the burned areas in summer and winter. Thus, having burned and unburned areas in tobosagrass pastures is desirable.

Northern Great Plains

In the northern mixed prairie, information for the arid areas (10 to 16 inches annual precipitation) indicates there may be only a limited place for fire as a management tool. However, fire is capable of killing silver sagebrush, fringed sage, and little club moss. More data is needed on the desired frequency of burning. Prescribed burning should probably be conducted in this region only during wet years. Fall burning appears to have the most promise for not injuring desirable forage species (Clarke et al, 1943).

In the moister areas (16 to 20 inches annual precipitation) of the northern mixed prairie, cool season grasses (except for slender wheatgrass and smooth brome) are more tolerant of fire and the warm season grasses (little bluestem and big bluestem) benefit from burning (Kirsch and Kruse, 1972). Shrubs (e.g., Symphoricarpos sp.) can be set back by fire (Bailey, 1978) and ponderosa pine seedlings can be killed (Gartner and Thompson, 1972).

Periodic prescribed burning can be used in fescue grassland to reduce litter buildup on ungrazed slopes, which aids better cattle distribution. Since shrubs can be only set back by one burn, reburns, periodic heavy grazing, or herbicide treatments are required to keep them in check. The effect of fire on wildlife is unknown. Prescribed burning should probably only be done during cycles of wet years and then only on a 5 to 10 year interval.

Tallgrass Prairie

The primary reasons for burning in the tallgrass prairie are to increase palatability, increase nutritional value of tallgrasses, suppress encroachment of trees and shrubs, and reduce competition from cool season plants. Annual burns do not harm the native warm season species if burned about May 1 (Anderson et al, 1970), but when burned less frequently, all of the major tallgrass species--big bluestem, little bluestem, Indiangrass, and switchgrass--increase after burning (Hensel, 1923; Aldous, 1934; Dix and Butler, 1954; Robocker and Miller, 1955; Kucera and Ehrenreich, 1962; Hadley and Kieckhefer, 1963; McMurphy and Anderson, 1965; Hulbert, 1969).

Cool season grasses are severely harmed by spring burning. Many researchers (Hensel, 1923; Ehrenreich, 1959; Hadley and Kieckhefer, 1962; Old, 1969) have found that Kentucky bluegrass decreases 80 percent or more following a spring burn. Curtis and Partch (1950) found that Canada bluegrass and Kentucky bluegrass were severely damaged by spring burning. Similarly, Canada wild rye and Virginia wild rye (Elymus virginica) (Robocker and Miller, 1955), Japanese brome (Bromus japonicus)

Carolina horsenettle (Solanum carolinense), and annual sunflower (Helianthus annuus). During the second growing season after burning, plains dozedaisy and redseed plantain (Plantago rhodosperma) reach their maximum importance value (Neuenshwander, 1976).

In west-central Kansas, Hopkins et al (1948) found that spring burning severely harmed wild onion (Allium nuttallii) and perennial broomweed (Xanthocephalum sarothrae), but left perennial ragweed (Ambrosia psilostachya) and goldenrod (Solidago mollis) unharmed. Launchbaugh (1964) found western ragweed and mare's tail to be somewhat harmed by spring burns, but burned plots were not significantly different from the controls.

Trees and Shrubs

The presence of mesquite (Prosopis glandulosa var. glandulosa) and other shrubs in the southern mixed prairie before the arrival of white man has been well documented in the journals of Marcy (1849) and Michler (1850). Mesquite was present throughout the entire southern mixed prairie on uplands as well as bottomlands in the Rolling Plains (mixed prairie). A map of Marcy's expedition shows vegetation marked as "mesquite timber" from Big Spring to the junction of the Clear Fork of the main Brazos River. This area was approximately 120 to 150 miles long and 50 miles wide. Throughout the rest of the Rolling Plains, explorers always talked about the continuous presence of mesquite, frequently as a low-growing shrub at the northern and southern extremities.

That fire was a part of the "mesquite timber" country has also been documented. After leaving the Double Mountain Fork and the Clear Fork of the Brazos on his way to the Big Spring, Michler (1850) gave the following description:

> "There was but little timber upon these streams upon first leaving the main fork, but the further we advanced the more we found, elm being the principal growth. The whole country was well timbered with mesquite, but most of it had been killed by prairie fires."

Evidently, this must have been a recent fire since Marcy and his command had traveled through the same country the previous year and did not mention the fire.

We have done a considerable amount of research on honey mesquite near Colorado City, Texas, which is in the "mesquite timber" country so designated by Marcy. Mesquite is moderately affected by fire depending upon its age, its history, weather at time of burning, and the amount of fine fuel for burning (Wright, 1972; Wright et al, 1976). Green mesquite trees are very difficult to kill with one fire unless they are very young. Young mesquite trees that were burned at temperatures above

200° F were easily killed by fire up to 1.5 years of age, severely harmed at 2.5 years of age, and very tolerant of fire after 3.5 years of age (Table 2).

Large mesquite trees that had previously been killed with 2,4,5-T were killed more easily than small trees with resprouts (Britton and Wright, 1971). This was because of the infestation with insect borer activity following the drouth of the '50's in the larger trees.

Trees previously topkilled by agents such as drouth, herbicides, etc., were moderately harmed by fire. Percent mortality of 1,200 trees that had resprouted after spraying in 1966 and were burned in 1969 was as follows:

	Year				
	1969	1970	1971	1972	1973
Mortality (%)	10.8	17.7	22.6	25.7	26.4

Table 2. Percent Mortality of Young Mesquite Trees After Burning in Relation to Age and Maximum Soil Surface Temperature.

	Temperature (F)				
Age (Years)	200	500	800	1100	Control
0.5	43	91	100	100	14
1.5	60	100	100	100	0
2.5	20	40	64	72	0
3.5	8	8	8	8	4
10 (Approx.)	0	0	4	8	0

The initial mortality was caused by the ignition of dead mesquite stems which served as a fuel source to burn into living crowns. For this kind of burning to take place, winds must be in excess of 8 mph and the relative humidity must be below 40 percent at the time of burning. Subsequent mortalities were caused by an interaction between a weakened condition caused by fire, drouth, competition from grasses, insect damage, and damage by rabbits and rats.

Juniper species are quite common throughout the prairie country on rocky slopes such as escarpments, ridges, or rimrocks (Wells, 1970) as well as on areas that have been protected from fire (Penfound, 1964). Arend (1950) found that in Oklahoma fire was the worst natural enemy of

eastern red cedar (Juniperus virginiana), a nonsprouting species. Similarly, Dalrymple (1969) and Wink and Wright (1973) have found Ashe juniper (J. ashei), another nonsprouting species, also very susceptible to fire in southern Oklahoma and central Texas. These species cannot maintain themselves in areas that burn frequently because the leaves are very flammable, especially during fall months, and the bark is so thin that heat from one surface fire usually kills all trees.

With 500 to 1,000 lb/acre of herbaceous fuel, Dalrymple (1969) obtained a 100 percent mortality of trees less than 2 ft tall, 77 percent mortality of trees 2 to 6 ft tall, and 27 percent mortality of trees over 6 ft tall, for an average mortality of 68 percent. Where fine fuel was at least 1,100 lb/acre, Wink and Wright (1973) found that 99 percent of the Ashe juniper trees less than 6 ft tall were killed by fire with the following weather conditions: air temperature 75 to 85° F, relative humidity 25 to 35 percent, and wind 10 to 15 mph. If fine fuel was above 2,500 lb/acre, all juniper trees were killed by fire. With 750 lb/acre of fine fuel, Dwyer and Pieper (1967) reported than 70 percent of the juniper trees exposed to high temperatures of a summer wildfire eventually died by the following year.

Redberry juniper (J. pinchoti), a sprouting species on rough breaks in the Rolling Plains, is very difficult to kill by fire unless the trees are under 12 years of age (Smith et al, 1975). However, fires reduce the sphere of influence of the trees. Once a tree is established, it dominates the area around it and very little forage grows under the tree. When the trees are burned, they dominate less area, and grasses and forbs encroach.

Several shrub species are present in the mixed prairie of the southern Great Plains, but they are less abundant than the tree species. One palatable species that thrives after fires is fourwing saltbush. It is a vigorous sprouter and appears to have fully recovered 3 years after a burn. In mesquite communities, lotebush also sprouts after a fire but regains its original position in a community about 6 years after a burn. Littleleaf sumac (Rhus microfolia) and algerita (Berberis trifoliata) sprout following fires, but we have relatively little research data on these species in West Texas. Smoothleaf sumac and all species of oak are vigorous sprouters in Ashe juniper communities of the Edwards Plateau.

Cacti are frequently present in high densities in mesquite-tobosa communities, but they are not well adapted to fire. Tasajillo (Opuntia leptocaulis) is easily killed by fire with 70 to 80 percent mortality (Bunting and Wright, 1978). Pricklypear (Opuntia phaeacantha) and walkingstick cholla (Opuntia imbricata) are also severely harmed by fire (Heirman and Wright, 1973; Bunting and Wright, 1978). All mortality of cactus species is the result of a fire-insect interaction, and frequently, animals (domestic and wild) also have an impact.

Fire Effects - Mixed Tallgrass - Forest

In east-central Texas and eastern Oklahoma, the cross timbers occupy a sandy belt of land that contains post oak and blackjack oak as well as many tallgrass prairie species, particularly little bluestem, in the understory. Both oak species are easily topkilled by fire but resprout vigorously. No fire research has been done in this area and it is not clear as to what the natural role of fire may have been. Presently, there is a lot of interest in the possibility of using fire on a 4-year rotation to keep the sprouts of oak suppressed since it is no longer economical to use goats or chemicals for this purpose in bluestem pastures.

Central Great Plains

Distribution, Climate, Soils, and Vegetation

The Central Great Plains extend from the foothills of the Rockies in eastern Colorado and southeastern Wyoming eastward through Kansas and Nebraska to grassland-forest combinations in northwest Missouri, southern Iowa, and Illinois. Shortgrass prairie lies primarily in eastern Colorado, but it is also found in western Kansas, southeastern Wyoming, and the extreme portion of western Nebraska. Precipitation varies from 11 to 18 inches per year. Surface soil textures are largely sand, sandy loam, loamy sand, loam and silt loam. Elevation drops from 5,000 or 6,000 ft along the foothills in Colorado to 3,000 ft on the eastern edge of the shortgrass prairie in Kansas. In Nebraska, the eastern elevations vary from 4,000 to 5,000 ft.

Dominant grasses on the sandy textured soils are blue grama, prairie sandreed (Calamovilfa longifolia), and needle-and-thread (Stipa comata). Other grasses include sun sedge (Carex heliophyla), red three-awn (Aristida longiseta), and sand dropseed (Sporobolus cryptandrus). Well managed ranges in eastern Colorado can also support sand bluestem (Andropogon halli), switchgrass (Panicum virgatum), and Indiangrass (Sorghastrum nutans). Dominant forbs and shrubs are western ragweed (Ambrosia psylostachya), bush morning glory (Ipomea leptophila), herbaceous sage (Artemisia ludoviciana), and fourwing saltbush.

On loams and silt loams, buffalograss, blue grama, western wheatgrass, and scarlet globemallow are the dominants. Ranges in good to excellent condition will also contain green needlegrass (Stipa viridula).

East of the shortgrass prairie lies tallgrass prairie in the Sand Hills of northwestern Nebraska and mixed prairie in the remainder of western Nebraska and Kansas. Elevation along the western edge of the mixed prairie in Kansas is 3,000 ft but rises to as much as 5,000 ft along the western edge of the Sand Hills in Nebraska. Along the eastern edge, elevation starts at 1,300 ft in southern Kansas and rises to as much as 2,000 ft in north-central Nebraska. Precipitation varies from 18 to

28 inches in Kansas and 18 to 23 or 25 inches in Nebraska. Topography varies from undulating to rolling ridgetops, gently sloping, and hilly with steeply sloping valley sides. Soil textures are sand, silt, loam, silt loam, silty clay loam, and clay uplands.

Dominant grasses in the mixed prairie of the Central Great Plains are blue grama, little bluestem, sand dropseed, tall dropseed (Sporobolus asper), western wheatgrass, buffalograss, sideoats grama, purple three-awn (Aristida purpurea), needle-and-thread, junegrass (Koelaria cristata), and occasional plants of sand bluestem, prairie sandreed, and switchgrass. Western wheatgrass and needle-and-thread become more prevalent as you go northward from Kansas into Nebraska. Common forbs include scarlet globemallow, western ragweed, resindot skullcap (Scutellaria resinosa), prairie coneflower, wreath aster (Aster multiflorus), black sampson (Echinacea angustifolia), prairie phlox (Phlox pilosa), prairie clover (Petalostemum purpureum), dotted gayfeather, few-flowered psoralea (Psoralea tenuiflora), Missouri goldenrod (Solidago missouriensis), and many others. On heavily grazed sites, western ragweed and annual sunflowers (Helianthus annuus) are abundant.

Tallgrass prairie in the eastern one-third of Nebraska, northern Iowa, and east-central Kansas varies in elevation from 1,000 to 2,000 ft. Annual precipitation varies from as low as 23 inches in eastern Nebraska to as much as 35 inches along the eastern edge of the tallgrass prairie. The Sand Hills in western Nebraska, a westward extension of the tallgrass prairie, has precipitation as low as 18 inches per year. Except for the Sand Hills of Nebraska and the Flint Hills of Kansas, most of the soils are medium textured. Soils in the Flint Hills are primarily Lithosols. Topography is gently rolling.

Grasses of the tallgrass prairies are primarily little bluestem, big bluestem, switchgrass, Indiangrass, and prairie dropseed (Sporobolus heterolepis). With these occur Canada wildrye (Elymus canadensis), porcupine grass (Spartina pectinata), and eastern gramagrass (Tripsacum dactyloides). Additional species in the Sand Hills of Nebraska include prairie sandreed and sand bluestem. Important shrubs include western snowberry (Symphoricarpos occidentalis), inland ceanothus (Ceanothus ovatus), lead plant, willow (Salix sp.), gooseberry (Ribes sp.), and prairie rose (Rosa arkansana). A wide variety of forbs occur in tall-grass prairie (Weaver and Clements, 1938; Weaver and Albertson, 1956). Typical genera include Aster, Solidago, Silphium, Helianthus, Astragalus, Baptisia, Callinhoe, Phlox, Sisyrinchium, Lithospermum, Viola, Anemone, Tradescantia, Psoralea, Erigeron, Petalostemum, Glycyrrhiza, Echinacea, Liatris, Vernonia, Coreopsis, Bidens, Kuhnia, and Carduus. Some trees grow in the tallgrass prairie. These include American elm (Ullmus americana), hackberry (Celtis occidentalis), eastern red cedar (Juniperus virginiana), bur oak (Quercus macrocarpa), cinquapin oak (Q. muhlen-bergii), eastern redbud (Cercis canadensis var. canadensis), bitternut hickory (Carya cordiformis), and roughlead dogwood (Cornus drummondii) (Smith and Owensby, 1972).

Tallgrass prairie and forest combinations extend eastward into eastern Kansas, northwestern Missouri, southern Iowa, and Illinois. The tallgrass species are the same as for the tallgrass prairie and the forest is oak-hickory (Quercus - Carya). Precipitation increases to as much as 40 inches per year and elevation drops to 500 ft.

Fire Effects - Shortgrass and Mixed Grass Prairie

No prescribed fires have been conducted in these plant communities in the Central Great Plains. The only references are those for wildfires by Hopkins et al (1948) and Launchbaugh (1964). These references were referred to earlier in the southern Great Plains section to compare the effects of fires during drouth years vs. wet years, when prescribed burning might be recommended. Following dry years, Hopkins et al (1948) found that the cover and yield of big bluestem, little bluestem, hairy grama (Bouteloua hirsuta), sideoats grama, buffalograss, hairy sporobolus (Sporobolus pilosus), and blue grama were reduced by fire, and undesirable broad-leaved plants, principally western ragweed, increased. Similarly, Launchbaugh (1964) found that buffalograss, blue grama, and western wheatgrass did not fully recover after fire until the third growing season.

Based on the data during wet years in the southern Great Plains, there does not seem to be any benefit in burning the shortgrass prairie unless there are unusual litter accumulations. So, it is difficult to justify research for prescribed burning in the essentially shrubless short grass prairie of the Central Great Plains. Most of the mixed prairie is plowed and planted to wheat, so again there is very little need for prescribed burning research.

Fire Effects - Tallgrass Prairie

Shantz and Zon (1924) have suggested that the eastern Plains, where the subsoil is permanently moist, may be an induced grassland (by fire and drouth) occupying an environment suited to trees. Work by Kucera (1960), Blan (1970), and Bragg and Hulbert (1976) support this theory. Aerial photography by Bragg and Hulbert (1976) in the Flint Hills bluestem prairie showed that on unburned pastures the combined tree and shrub cover increased 34 percent from 1937 to 1969. Tree cover alone increased 24 percent from 1856 to 1969. Invasion by trees was greatest on the deep, permeable, lowland soils; woody plants increased only slightly on the drouthy upland soils. Based on this data, Bragg and Hulbert (1976) concluded that burning had been effective in restricting woody plants to natural, presettlement levels. For Minnesota and Nebraska, however, Weaver (1954) concluded that "over most of the territory it seems probable that shrubs and woodland could not extend their areas greatly even if unhandicapped by mowing and prairie fires."

The incentive for burning in the Flint Hills of Kansas was stimulated by lease arrangements in the 1880's for transient steer grazing. Lessees required that the lands be burned (Kollmorgen and Simonett, 1965) because the forage had higher nutritional value after burning. Livestock gains were 25 lb/steer higher on late spring burns than on adjacent unburned pastures (Smith and Owensby, 1972) and growth began 7 to 10 days earlier on burned plots (Kucera and Ehrenreich, 1962). Also, Penfound and Kelting (1950) demonstrated that cattle will eat more little bluestem if it is burned.

Grasses

The effect of fire on grasses depends on the site, the amount of moisture, and the frequency of burning. However, there is reasonably good agreement among many authors about the effect of fire on grasses in the tallgrass prairie. Big bluestem (Andropogon gerardii) almost always increases after burning. Hadley and Kieckhefer (1963) noted a 275 percent increase in big bluestem one year after burning in Illinois. Other researchers who have noted an increase in big bluestem include Robocker and Miller (1955), Kucera and Ehrenreich (1962), McMurphy and Anderson (1965), Hulbert (1969), and Anderson et al (1970). Likewise, Indiangrass (Sorgastrum nutans) always increases after burning (Dix and Butler, 1954; Roboker and Miller, 1955; Kucera and Ehrenreich, 1962; Hadley and Kieckhefer, 1963; Anderson et al, 1970).

Switchgrass (Panicum virgatum) has not been studied as intensively as the previous two species. However, in one study where the species was present in burned plots, Robocker and Miller (1955) found that it increased. In another study by Anderson et al (1970), there was relatively little in the plots and no change was detected. Based on another study where mulching was applied to plots, the yields decreased with increased mulching (Weaver and Rowland, 1952).

Little bluestem also generally increases after fire in the true prairie. Increases have been noted by Hansel (1923), Aldous (1934), Penfound and Kelting (1950), Dix and Butler (1954), Robocker and Miller (1955), and Kucera and Ehrenreich (1962). Anderson et al (1970) found no change in the production of little bluestem after 8 years of consecutive annual burning, provided the burns were conducted in late spring (May 1). Early spring (March 20) burns reduced yields as much as 25 percent (McMurphy and Anderson, 1955; Owensby and Anderson, 1967). Soil moisture has to be considerably below normal in this rainfall zone to harm little bluestem (Box and White, 1969).

Sideoats grama generally shows no change after burning (Hensel, 1923; Robocker and Miller, 1955; Anderson et al, 1970; Smith and Owensby, 1972). Other grasses which have been shown to increase following early spring or winter burning include prairie junegrass (Koeleria cristata) (McMurphy and Anderson, 1965), prairie sand dropseed (Hensel, 1923),

blue grama, and hairy grama (Anderson et al, 1970). Buffalograss shows no change after consecutive annual burns (Anderson et al, 1970).

Cool season grasses are severely harmed by spring burning. Many authors (Hensel, 1923; Ehrenreich, 1959; Hadley and Kieckhefer, 1963; Old, 1969) have found that Kentucky bluegrass (Poa pratensis) decreases from 80 to 100 percent following a spring burn. Curtis and Partch (1948) found that Canada bluegrass (Poa compressa) and Kentucky bluegrass were severely damaged by spring burning. Similarly, Canada wild rye (Elymus canadensis) and Virginia wild rye (Elymus virginica) (Robocker and Miller, 1955), Japanese brome (Bromus japonicus) (McMurphy and Anderson, 1965), and smooth brome (Bromus inermis) (Old, 1969) are all damaged by fire. Species such as smooth brome which begins growth about mid-May are only inhibited by burning, whereas species such as Kentucky bluegrass are almost eliminated by burning because they begin growth in early April (Old, 1969). Fall witchgrass (Leptoloma cognatum) is favored by fire (Penfound, 1964).

Kucera (1970) proposes a 3-year interval between burning to maintain grass dominance, as well as to retain the species diversity typical of the native prairie community.

Forbs

Late spring burning reduces all forbs (McMurphy and Anderson, 1965), although the composition of forbs is changed relatively little (Anderson, 1965). Major forbs that are harmed by fire include Petalostemum species (Hadley, 1970), heath aster (Aster ericoides) and Solidago species (Kucera and Koelling, 1964). Plains wild indigo (Baptisia leucophilia) (Anderson, 1965) is favored by fire.

In Nebraska Sand Hills, Wolfe (1972) found that a spring wildfire reduced herbage growth as much as 45 percent in a prairie sandreed-bluestem association. Most of the forbs that increased were decreasers, and those that decreased were increasers. Forbs increasing included prairie sunflower (Helianthus petiolaris), dotted gayfeather, Missouri goldenrod, false boneset (Kuhnia eupatorioides), and sikly prairie clover (Petalostemum villosum). Those that decreased were pepperweed (Lepedium sp.), Virginia dayflower (Commelina virginica), woolly plantain, goosefoot, prairie coneflower, pigweed (Amarantus sp.), and gromwell (Lithospermum sp.). Western ragweed and Missour spurge (Euphorbia missourica) remained unchanged.

Shrubs and Trees

There are a relatively few species of shrubs in the true prairie. However, several shrubs are favored by fire. These include smoothleaf sumac, lead plant (Amorpha canescens) (Anderson et al, 1970), and western snowberry (Symphoricarpos occidentalis) (Pelton, 1953). Buck-brush (Symphoricarpos orbiculatus) is slightly harmed by fire and can be

controlled with annual spring burning (McMurphy and Anderson, 1965). Nevertheless, if protected after burning, buckbrush will increase dramatically.

Eastern red cedar (Juniperus virginiana) and western snowberry will invade a prairie protected from fire (Penfound, 1964). American elm (Ulmus americana) seedlings establish easily after a burn (McMurphy and Anderson, 1965). However, a later fire will remove the seedlings.

Seed Yields

Several articles (Burton, 1944; Curtis and Partch, 1950; Kucera and Ehrenreich, 1962; Old, 1969) show that herbage removal or burning increases flower stalk production. Burton (1944) reported an increase in seed yield in burned areas, grazed, and mowed prairie compared with ungrazed, unburned areas. Curtis and Partch (1950), working in Wisconsin, reported a six-fold increase in flowering on clear-cut sites when compared to unburned areas, and this increase was equivalent to that on recorded burned areas. Kucera and Ehrenreich (1962) also found that flower stalks were more numerous on burned areas. The main species affected were big bluestem, little bluestem, and Indiangrass. Quadrat counts in 1960 showed percentage increases due to burning of 270, 1,200, and 400 respectively.

A detailed study of the effect of litter and burning on flower stalk production was conducted by Old (1969). Flowering on clipped and raked areas was 50 percent lower than on a current year's burn. This data indicates that, in addition to litter, removal of competition by cool season plants, and increased soil temperatures after fire stimulated nitrification which increased seed yields. The addition of ash had no effect, but adding 200 lb/acre of nitrogen significantly increased seed yields over the burn. Below is a tabulation showing the effect of burning and various litter treatments on flowering:

Treatment	Number of Flower Stalks	
	1967	1968
First year after burning	102	74
Clear-cut	66	63
Cut and left	29	52
Undisturbed	11	34

Litter

Prairie closed to both grazing and fire soon begins to deteriorate (Anderson et al, 1970). Accumulation of mulch depresses herbage yield

and reduces the number of plant species (Weaver and Tomanek, 1951; Ehrenreich, 1959). Most of this decrease is associated with lower soil temperatures (Peet et al, 1976).

Reduced herbage yield, as litter increases, is partially related to the amount of ammonium nitrogen. Rice and Pancholy (1973) found that the amount of ammonium nitrogen was lowest in the first successional stage, intermediate in the intermediate successional stage, and highest in the climax. The amount of nitrate was highest in the first successional stage, intermediate in the intermediate successional stage, and lowest in the climax. This data indicates that the nitrifiers are inhibited in the climax stage so that ammonium nitrogen is not oxidized to nitrate as readily in the climax as in the successional stages.

Northern Great Plains

Distribution, Climate, Soils and Vegetation

The Northern Great Plains include the eastern two-thirds of Montana, eastern one-third of Wyoming, North Dakota, South Dakota, and the western edge of Minnesota. A large part of Minnesota, however, is a mixture of grassland and forest communities. There are no shortgrass associations, only mixed prairie and tallgrass prairie. The mixed prairie includes eastern Montana, eastern Wyoming, and all but the eastern edges of North Dakota and South Dakota. Precipitation varies from 10 to 20 inches, with the driest areas being on the western edge of the mixed prairie. Soil textures are primarily sand, sandy loam, silt loam, silty clay loam, and loam. Elevation varies from 1,300 to 4,100 ft. The highest elevations occur in eastern Wyoming and southeastern Montana. From this high rolling topography, elevation drops to 3,000 ft in northern Montana and then to 1,300 ft in eastern South Dakota and North Dakota. Topography in northern Montana and the central Dakotas is level to gently rolling.

Grasses in eastern Montana and Wyoming are mainly blue grama, needle-and-thread, green needlegrass, western wheatgrass, bearded wheatgrass (*Agropyron dasystachyum*), threadleaf sedge (*Carex filifolia*), Sandberg's bluegrass (*Poa secunda*), plains muhly (*Muhlenbergia cuspidata*), and junegrass, with occasional amounts of little bluestem and prairie sandreed. In the foothills of central and southern Montana, rough fescue (*Festuca scabrella*) will also be a principal dominant. Forbs are not very abundant, but pussytoes (*Arenaria* spp.), prairie phlox (*Phlox pilosa*), little club moss (*Selaginella densa*), scarlet globemallow, black sampson, and silverleaf psoralea (*Psoralea argophylla*) are representative species. Shrubs are predominantly fringed sagebrush (*Artemisia frigida*), herbaceous sage, Nuttall's saltbush, winterfat (*Eurotia lanata*), and plains pricklypear.

In western North Dakota and South Dakota, the grass species are very similar to eastern Montana and Wyoming with perhaps more little bluestem, some green needlegrass, and the addition of western

(McMurphy and Anderson, 1965), and smooth brome (Old, 1969) are all damaged by fire. Species such as smooth brome, which begins growth about mid-May, are only inhibited by burning, whereas species such as Kentucky bluegrass are almost eliminated by spring burning because they begin growth in early April (Old, 1969).

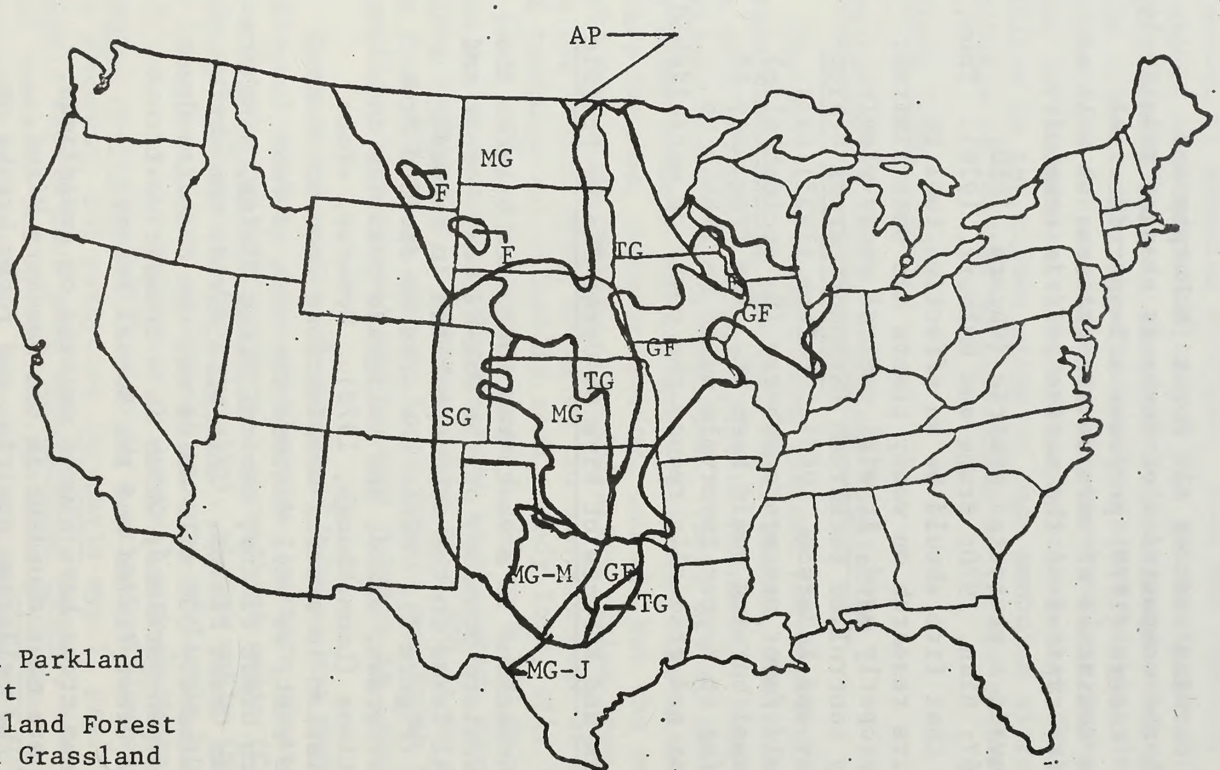
Late spring (May 1) burning reduces all forbs (McMurphy and Anderson, 1965), although the composition of forbs is changed relatively little (Anderson, 1965). Kucera (1970) proposes a 3-year interval between burns to maintain dominance of warm season grasses, as well as to retain species diversity typical of the native prairie community.

Woody plants will invade a protected prairie (Kucera, 1960; Penfound, 1964; Vogl, 1967; Blan, 1970; Bragg and Hulbert, 1976). Thus, it only seems reasonable that fire should be an effective tool to control woody plants. Fire research on woody plants has been limited, but it appears that, if properly used, it will control woody plants. Annual burning during May controlled buckbrush (Symphoricarpos orbiculatus) in Kansas (McMurphy and Anderson, 1965). Pelton (1953) felt that periodic burning would favor western snowberry (S. occidentalis) in Minnesota but that annual burning would harm it. The frequency of fire is important. Burning at 3-year intervals would be likely to prevent tree establishment and gradually reduce the cover of established shrubs and trees.

Ecological Characteristics and Effects of Fire on Great Plains Prairie Communities

The North American Grassland is a vast area that lies between the Rocky Mountains and the western boundary of the Oak-Hickory Forest and extends from south-central Texas to the aspen-parkland in central Alberta and Saskatchewan (Figure 1). Often the area is divided from west to east into the shortgrass, mixed, and tallgrass prairies and grassland-forest combinations (Launchbaugh, 1972). However, since there is such a wide variation in species combinations from north to south, as well as west to east, we will discuss the area as four geographic units--southern Great Plains, central Great Plains, northern Great Plains, and Canadian Great Plains. This will divide the north-south regions into approximately 500 mile units and the Canadian Great Plains will include the aspen-parkland, which is a transitional zone of vegetation between the Great Plains and the Boreal Forest.

In general, shrubs and trees have always existed on grasslands. In the Great Plains they are most abundant in the Southern Mixed Prairie, eastern edge of the tallgrass prairie, and rocky breaks or heavily grazed areas where fires are the least frequent. Drouths can control the abundance of shrubs where grass is healthy, but the shifts from grasslands to shrubs and trees may occur on a 100-year cycle if the climate is the only factor. With fire as a factor, as it seems to have been in the past, shrub and tree growth is restricted (Malin, 1953) because fire triggers a significant interaction with other factors.



AP	Aspen Parkland
F	Forest
GF	Grassland Forest
MG	Mixed Grassland
MG-J	Mixed Grassland-Juniper-Oak
MG-M	Mixed Grassland-Mesquite
SG	Short Grassland
TG	Tall Grassland

Fig.1. Map of natural vegetation of Great Plains grasslands from Kuchler(1965).

Fire effects for the Plains and Prairies are presented in tabular form and are grouped by major plant community:

FIRE EFFECTS

SOUTHERN GREAT PLAINS

Shortgrass Prairie

Species	Fire Effects	Remarks
Buffalograss Blue grama	Decreased for 2 to 3 years after burning during drouth years; Buffalograss and blue grama not harmed when winter and spring precipitation are above normal.	
Red three-awn Sand dropseed	Generally decreased by fire Generally decreased by fire	But tolerant when winter and spring precipitation were 40% above normal.
Galleta Ring muhly Slim-Stemmed muhly Wolf-tail	Generally decreased by fire	Based on data from wildfire during a below average precipitation year
Little bluestem	Production decreased after burn	Based on data from sand shinnery oak areas in Oklahoma.
Tumble windmill grass	Not harmed by fire	
Sand bluestem Switchgrass Weeping lovegrass	Production increased after burn Production increased after burn Not harmed by fire	Based on data from sand shinnery oak areas in Oklahoma.
Annual broomweed Horsetail Silverleaf nightshade Western ragweed	Harmed by spring burning	Generally, forbs are harmed more by spring burns than fall burns.
Rabbit's tobacco Warty euphorbia Woolly plantago	Not affected by spring burning	
False mesquite	Favored by spring burning	

SOUTHERN GREAT PLAINS

Shortgrass Prairie

Species	Fire Effects	Remarks
Mesquite	Fire tolerant	Exceptional sprouters, especially on the High Plains. Seedlings reasonably tolerant of fire when they are over one year old. A February burn reportedly killed 31% of seedlings less than one year old. Repeated burns will keep mesquite in check.
Shinnery oak	Fire tolerant	Increased 15% following fire, but produced no acorns during year of burn.
Algerita Aromatic sumac Chickasaw plum Fourwing saltbush Skunkbush sumac Winterfat	Fire tolerant sprouters	Fourwing saltbush is palatable and is fully recovered 3 years after being burned.
Sand sage	Fire intolerant	Is killed by fire, but produces abundant seedlings after burning.
Cacti (Opuntia)	Fire intolerant	50 to 80% of most species are killed, especially if they are less than 2 ft tall. Large clumps of pricklypear or tall cholla usually survive fires.
Mixed Prairie		
Sideoats grama (rhizomatous form)	Intolerant	More tolerant in wet years - yield decreased 51% in dry years vs. 12% in wet years. Takes at least 3 years to recover after being burned during dry years.
Little bluestem	Tolerance is moisture dependent	Decrease about 50% dry years, but will increase as much as 81% during wet years after a spring burn.
Tobosagrass	Very tolerant	Burning increases production 2 to 3-fold and palatability 10-fold when precipitation is average or higher. When precipitation is below average, yields may be reduced 20 to 50%. Never burn more than 1/5 to 1/8 of a pasture each year.

SOUTHERN GREAT PLAINS

Mixed Prairie

Species	Fire Effects	Remarks
Arizona cottontop Meadow dropseed Plains bristlegrass Texas cupgrass Vine mesquite	Tolerant	Thrive after fire when moisture is adequate. Vine mesquite shows increased yields for 2 years; Arizona cottontop for 1 year.
Tall grama	Intolerant	Tolerates fire after burns in wet years; declines as much as 60% during dry years.
Sideoats grama-bunchgrass form	Tolerant	
Texas wintergrass	Intolerant	Severely harmed by broadcast fires, but favored by cool, creeping spring ground fires.
Little barley Carolina canary grass	Intolerant of spring burning	Cool season annual grasses.
Annual broomweed Bitterweed Scarlet globemallow Wild onion	Intolerant	
Annual sunflower Carolina horsenettle Lambsquarter Silverleaf nightshade	Common on burns	
Plains dozedaisy Redseed plantain	Tolerant	Second season after burning plains dozedaisy and redseed plantain maximum importance value.
Perennial ragweed	Tolerant	
Goldenrod	Tolerant	

SOUTHERN GREAT PLAINS

Mixed Prairie

Species	Fire Effects	Remarks
Mesquite	Tolerance dependent on age, stand history, weather, fire intensity	Green mesquite tolerant except when very young. Temps. greater than 200°F - plants up to 1.5 yrs. easily killed; 2.5 yrs. old - severely harmed. 3.5 yrs. and older - very tolerant.
		Trees previously top killed (drouth, herbicides, etc.). Moderately harmed -- 25% mortality on upland sites; none along river bottoms.
Eastern red-cedar	Intolerant	Nonsprouter - leaves very flammable; bark very thin; seedlings abundant after fire.
Ashe juniper	Intolerant	Nonsprouter - leaves very flammable; bark very thin; seedlings abundant after fire. Amount of mortality depends on amount of fine fuel and fire intensity.
		Minimum fine fuel needed to kill trees 2 to 4 ft high is about 1,000 lb/acre of fine fuel. With 2,500 lb/acre or more, all juniper trees will be killed.
Redberry juniper	Tolerant when over 12 yrs. old	Sprouter. Fire reduces "sphere of influence" - permits grasses and forbs to become established closer to trees.
Lotebush	Tolerant; regrowth is slow until 4th year after burning	Sprouter - regains prefire position in about 6 to 10 years after fire.
Fourwing saltbush	Very tolerant	Palatable species, vigorous sprouter - fully recovered 3 yrs. after burn.
Algerita) Littleleaf sumac) Oak)	Tolerant	Sprouters - little research data available.
Smoothleaf sumac	Very tolerant	Usually comes back on hottest areas of a burn; vigorous sprouter.
Cacti	Intolerant	Frequently present in high densities in mesquite-tobosa communities. Easily killed by fire (50-80% mortality). Fire acts as agent to initiate interactions that result in mortality; e.g., insect activity, rodent activity, drouth.

SOUTHERN GREAT PLAINS

Mixed Tallgrass-Forest

Species	Fire Effects	Remarks
Little bluestem	Tolerant	No fire research has been done. Interest current in using fire on 4 yr. rotation to keep oak sprouts suppressed in bluestem pastures. Based on this precipitation zone and fire effects data from other areas, little bluestem should be very tolerant to fire.
Blackjack oak Post oak	) Easily top-killed but resprout) vigorously	

CENTRAL GREAT PLAINS

Short Grass and Mixed Prairie

Species	Fire Effects	Remarks
Buffalograss Blue grama Western wheatgrass	Allow 2 to 3 yrs. for recovery during dry years; not harmed when precipitation is above normal	Buffalograss-blue grama mixture recovered 35, 62, and 97% following the first, second, and third growing seasons after being burned in the spring during a dry year. Western wheatgrass recovered 18, 27, and 77% respectively during the same growing seasons.
Big bluestem Hairy grama Hairy sporobolus Little bluestem Sideoats grama	Harmed by fire during dry years	No data for wet years, but would probably tolerate fire.

See data for Southern Great Plains

Tallgrass Prairie

Species	Fire Effects	Remarks
Big bluestem Indiangrass Little bluestem Switchgrass	Very tolerant	Production often doubles after burning, unless burned annually. If burned annually, burns should be conducted about May 1. Drouth is rarely a problem in this rainfall belt.
Blue grama Buffalograss Hairy grama Prairie junegrass Prairie sand dropseed Sideoats grama	Generally no change to a slight increase	

CENTRAL GREAT PLAINS

Tallgrass Prairie

Species	Fire Effects	Remarks
Canada bluegrass Kentucky bluegrass	Severely harmed	Generally an 80% reduction. Cool season species.
Canada wildrye Japanese brome Smooth brome Virginia wildrye	Harmed	Smooth brome is more tolerant to early spring burns than other cool season species because it does not germinate until mid-May.
Fall witchgrass	Favored	
Dotted gayfeather False boneset Missouri goldenrod Plains wild indigo Prairie sunflower Silky prairie clover	Tolerant	Most species favored by fire, but some people have reported decline for prairie clover and goldenrod.
Goosefoot Gromwell Heath aster Pepperweed Pigweed Prairie coneflower Virginia day flower Woolly plantain	Harmed	
Missouri spurge Western ragweed	Unchanged	

NORTHERN GREAT PLAINS

Mixed Grass Prairie

Species	Fire Effects	Remarks
Bearded wheatgrass Blue grama Green needlegrass Needle-and-thread	Frequency reduced by spring burning	
Pennsylvania sedge Prairie sandreed	Frequency unchanged by spring burning, but harmed by late summer fires.	
Carex eleocharis Junegrass Muhlenbergia Threadleaf sedge Western wheatgrass	Frequency unchanged or increased by spring burning	Increase in frequency does not imply increase in herbage yield, which might have been reduced for several years.
Big bluestem Little bluestem	Probably not harmed by fire and could be burned during years with normal to above normal precipitation to control scrubby ponderosa pine and undesirable shrubs.	
Silverleaf psoralea	Frequency significantly reduced by spring burning	Frequencies of most forbs remained unchanged after spring burning.
Leafy spurge Little club moss	Frequency reduced by fall burn	Data taken 4 years after a fall fire.
Hairy golden aster Wild lettuce	Harmed by late summer fire	
Hedeoma hispida Stickseed	Increased after fall burning	Data taken 4 years after a fall fire.

NORTHERN GREAT PLAINS

Mixed Grass Prairie

Species		Fire Effects	Remarks
Arkansas rose	)		
Fringed sagebrush	)	Reduced by spring burning	
Silver sagebrush	)		
Herbaceous sage	)	Increased after spring burning	

Tallgrass Prairie (True Prairie)

Species		Fire Effects	Remarks
Big bluestem	)		Some of this information is based on frequency data and may or may not reflect yields.
Blue grama	)		
Indiangrass	)		
Leiberg panicum	)		
Little bluestem	)	Increased after spring burning	
Prairie cordgrass	)		Eastern North Dakota study.
Prairie dropseed	)		
Prairie sandreed	)		
Saltgrass	)		
Wheatgrasses		Increased on upland sites, but declined on lowland sites.	
Bearded wheatgrass	)		
Canada bluegrass	)		
Foxtail barley	)		
Junegrass	)		
Kentucky bluegrass	)	Usually harmed by fire, but some data shows no change and some shows an increase	
Muhlenbergia sp.	)		
Quackgrass	)		
Rushes	)		
Slender wheatgrass	)		
Smooth brome	)		

NORTHERN GREAT PLAINS

Tallgrass Prairie (True Prairie)

Species	Fire Effects	Remarks
Erigeron Goldenrod Ragweed Rattlesnake master Tall gayfeather	Increase after spring burning	See Table 3 of Chapter VIII for other forbs that increase after burning.
Atlantic wild indigo	No change	
Heath aster	Variable responses	Declined in eastern North Dakota, but increased with spring burning in Wisconsin.
Canada thistle *Oxalis stricta* Prairie clover Purple coneflower *Trifolium repens* Wild parsnip	Declined after spring burning	
Arkansas rose Western snowberry	Increase after spring burning	
Scrub oak	Increases with fire exclusion	

CANADIAN GREAT PLAINS

Species	Fire Effects	Remarks
Agropyron-type communities Blue grama - Needle-and-thread communities	Reduced yields up to 50% following spring burning during a dry year. Effects of fall burning less pronounced - production decreased by 30% first year with recovery second year.	Agropyron-type communities more sensitive to spring burning than blue grama and needle-and-thread.
Bearded wheatgrass Slender wheatgrass Western porcupine grass	No change in cover after spring burn with good moisture; fall burns harmful	Fall burning severely harmed the wheatgrasses. Western porcupine grass was reduced 25 to 30% by fall burns.
Prairie sandreed Sedge	Increased with annual spring burns	
Hooker's oatgrass Parry oatgrass Rough fescue Sedge Timothy	Harmed by spring burning.	Rough fescue required 3 years for full recovery. It tolerates fall burns better than spring burns.
Bedstraw Bushpea Milk vetch Missouri goldenrod Stickseed Three-flowered avens Western yarrow Woundwort	Increased after spring and/or fall burning	
Little club moss	Seriously harmed by spring and fall burns	
Fringed sage Silverberry Silver sagebrush	Seriously harmed by spring and fall burns	

CANADIAN GREAT PLAINS

Species	Fire Effects	Remarks
Arkansas rose) *Rosa acicularis*) Western snowberry)	Moderately harmed	Desired frequency for shrub control is probably 5 to 10 years. Forage losses can be minimized by using fire only during those springs preceded by normal to above normal precipitation.
Herbaceous sage) Raspberry)	Increased dramatically	

Prescription Guides

for

Plains and Prairies

Following a list of printed instructions will not teach you how to ride a bicycle. You must get on the bicycle and practice to learn to ride it. However, having learned something of the feel of riding a bike, the novice rider can read or listen to more experienced riders on ways to improve his riding, increase efficiency of effort, speed, ease, comfort, or satisfaction. The same is true for learning how to conduct prescribed burns.

There is a lot of "art", and there are a lot of unforeseen circumstances that are peculiar to each burn. Nevertheless, experience is the best teacher. We learn by doing. And by doing we learn rapidly. An experience with a wildfire can be frightening, but prescribed burning is not as dangerous as wildfires. It is just dangerous to be inexperienced! And it is very dangerous to be half-experienced, for in this situation the person who becomes overconfident will have fires get away from him.

Models for prescriptions can be helpful in the planning phases of a burn, but they don't protect you against the intangibles--a hill on the side of a pasture that might cause unusual winds, a canyon on the lee side that may aid the formation of an intense firewhirl that will throw firebrands at greater distances than normal, unusual fuel densities that can create intense firewhirls, possibility of a night-time low-level jet of wind at 3,000 ft. elevation, volatile fuel material, etc. Generally, most people who conduct fires consider most fire danger index models, etc., to be too complicated and too time consuming to be useful. They usually use two to four variables in the decision making process as to whether or not burn.

The secret to all prescribed burning is to let the weather do the work for you. When all environmental factors are right, the job is easy. However, if the relative humidity is below 20 percent, if you are depending on a low pressure trough in late afternoon for your wind direction, if air temperature is above 80° F, or if average wind speeds are above 15 mph, prescribed burning can be a miserable job. On the other hand, don't be too cautious. Set a fire that will accomplish your objectives. The prescription that we like for most headfires is a relative humidity of 25 to 40 percent, air temperature 70 to 75° F, and wind 10 mph (over 8 mph). For backfires, you can use considerably cooler conditions, depending on amount of fine fuel moisture. We will give examples later.

In volatile fuels most firebrands ignite on punky wood, a cow chip, or lodge in a crack of bark, wood, or a tight clump of grass. Punky

wood and cow chips are by far the greatest concern. Your best defense is high humidity and a wide fireline. For example, we have never seen a glowing ember start a fire when the relative humidity was above 50 percent. Below a relative humidity of 20 percent, spot fires are numerous. Thus, we prefer to burn on the high side of the 20 to 40 percent range to minimize danger from firebrands. If you burn with a relative humidity above 40 percent, consumption of dead material, particularly standing material, will be reduced considerably.

Low wind speeds (below 6 mph) also reduce the risk of glowing firebrands starting spot fires. But, unless prescribed burning wind speeds are above 8 mph in grasslands, woody material will not ignite easily, and, if ignited, may go out. Again, this is most applicable for standing material.

Relative humidity is related to temperature, but we have had a tendency to rely more heavily on relative humidity than temperature. However, 67° F seems to be a threshold value. Below this temperature we usually get poor burns on woody materials. Above 75° F we must be very careful; we don't recommend burning when the air temperature is above 80° F.

Every fire is different and there is always a need for some experience in a fuel type before a person feels comfortable. When you are inexperienced in a vegetation type, seek out the best information available for that type of vegetation. Start small and start under less than ideal conditions--50 to 60 percent relative humidity, no wind, air temperature 50 to 60° F. Burn in late afternoon or early evening when you know the relative humidity is on the rise. Start a few small experimental burns, learn something about fire behavior, and what will burn. Document weather and fuel moisture for each burn.

<u>Mixed Prairie with Honey Mesquite</u> (low volatile fuel)

Detailed prescriptions for conducting burns in low volatile (mesquite-tobosagrass) and high volatile (Ashe juniper) fuels have been given by Wright (1974). Depending on the objectives, a wide variety of prescriptions can be used and experience is the best teacher. For example, if you want to clean up chained debris in buffalograss (<u>Buchloe dactyloides</u>) that has 2,000 lb/acre of fine fuel, burn out a 100 ft. fireline on the north and east sides when the relative humidity is 30 to 50 percent, wind is 5 to 10 mph, and air temperature is 60 to 75° F. Burn the rest of the pasture with a headfire when the relative humidity is 20 to 40 percent, wind is out of the southwest at 8 to 15 mph, and air temperature is 70 to 75° F.

If dead mesquite is standing and you wish to burn it down, you need a minimum of 4,000 lb/acre of fine fuel, relative humidity below 40 percent, and wind in excess of 8 mph. Burn out a 100 ft. fireline on the north and east sides with the relative humidity at 50 to 60

percent and the wind at less than 8 mph. Headfire the rest of the pasture with a southwest wind when the relative humidity is 25 to 40 percent, wind is 8 to 15 mph, and air temperature is 70 to 75° F.

The primary dangers in burning grasslands come from tumbleweeds and firewhirls. Tumbleweeds will ignite and then tumble, leaving flames in their path. Firewhirls develop where wind shears occur, such as when a headfire runs into a backfire, or a fire goes up slope into a wind. We have seen several firewhirls develop when headfires met backfires while winds were 10 to 15 mph. We have also seen two huge firewhirls develop when winds were light and variable. For these reasons, we prefer to burn with a steady wind and never burn into backfires, unless we have a least a 300 ft. fireline. Burning should be done parallel to ridges, not across them.

<u>Mixed Prairie with Juniper</u> (volatile fuel)

For chained or piles of dead juniper, firebrands are a serious problem. Plan on burning out a 400 ft. fireline on the north and east sides of a pasture. Burn out the dead piles of brush when the grass is green (May to early June), when the wind is less than 10 mph, and when the relative humidity is above 45 percent. Later (January or February), burn out the bluestem grass in the firelines when the relative humidity is 50 to 60 percent and the wind is less than 8 mph. Nonflaming firebrands are rarely a problem when the relative humidity is above 50 percent (Bunting and Wright, 1974). Where buffalograss occurs, you will need more wind and less humidity.

After the fireline is burned out, burn the rest of the area with a southwest wind when the relative humidity is 25 to 40 percent, wind is 8 to 15 mph, and air temperature is 65 to 75° F. If there has been a recent rain, wait to burn for at least 5 days after the rain.

For safety, avoid burning backfires into headfires and don't burn across ridges. Firewhirls can easily develop. In highly volatile fuels, burn into heavily grazed pastures, when possible, to minimize risk. No person should be given prescribed burning responsibilities in this fuel type at the operational level with less than two seasons of burning experience.

To burn grasslands with young, green juniper trees (2 to 5 ft. tall), one can use smaller firelines--about 50 ft. In these cases we usually cut a 10 ft. fireline around the entire pasture. Then burn out 50 ft. on the lee sides in late evening or early morning and put the fire out on the windward side with a pumper.

Sand Shin Oak with Little Bluestem (moderately volatile)

Burning techniques for this type in Oklahoma have not been documented. Generally there is enough grass so that the fire can back through the shinnery under cool conditions (i.e., relative humidity 50 to 60 percent, air temperature 60° F, and wind 5 to 10 mph). In many cases the fire would go out as it backs up. After a 200 to 300 ft. fireline has been burned, the area could be headfired.

Refinement of technique is needed in this fuel type. Oak leaves are good firebrands, so one has to be reasonably careful. However, based on our experience, we have never had trouble with oak leaves beyond 50 ft. We suspect that a 200 ft. fireline would be adequate to use headfires when the relative humidity is 25 to 40 percent, wind 5 to 10 mph, and air temperature 70 to 75° F. With 2,000 to 4,000 lb/acre of fine fuel, cooler conditions would give satisfactory burns. Based on volatile fuel data, the firelines should be burned when the relative humidity is above 50 percent, wind less than 8 mph, and air temperature is 45 to 65° F. The high humidity would be especially important to minimize danger from firebrands.

Firelines should be cut around the area to be burned, but inside of the 200 ft. strips could be natural breaks. Often the fire will go out when backing up and a pumper could be used to put out the spots that continue to burn.

Tallgrass Prairie

In the tallgrass prairie, particularly the Flint Hills region, many ranchers in the area have been burning for years and know how to burn. Thus, there has been essentially no need to document prescriptions for the kind of burning that they do.

Dr. Clinton Owensby in the Department of Agronomy, Kansas State University, Manhattan, Kansas is preparing a bulletin that contains prescription guidelines. He said that they don't have firebrand problems, except for some areas with red cedar, and their humidity is almost always 50 to 60 percent so that burning is pretty safe. Fine fuel is continuous and may be as much as 3,000 to 4,000 lb/acre.

They begin burning on the leeward sides of a pasture and initially let the fire back into the pasture. Concurrently they use two spray rigs to patrol and lay down a wet line when necessary. Usually they can backfire off a trail or road. They rarely plow permanent firelines. After the fire has backed up to 100 to 150 ft., they headfire the rest of the pasture. Headfires are conducted with 5 to 10 mph winds if improvement of forage quality is their only concern. Where brush

control is important, they use winds from 5 to 15 mph and try to burn when the relative humidity is around 40 percent. Temperature is not a consideration for burning, but generally varies from 60 to 75° F.

Where red cedar is a problem and they want to burn tall trees, they usually rest the pasture to be assured of 3,000 to 4,000 lb/acre of fine fuel. Then they burn out a 100 to 200 ft. fireline either late in the evening or early in the morning when some dew is on the grass. After the fireline has been burned, they use a headfure with winds up to 15 mph and low humidity (40 percent or so). Buckbrush has not given them any firebrand problems, so no special preparations are made when this shrub is present.

Marsh Burns

Marsh burns are usually conducted to thin out density of reeds, create new feeding areas, and to create more edge effect for nesting areas. In the north-central Nebraska Sand Hills, Schlichtemeier (1967) found that thick, dense stands of marsh could easily be burned with excellent results after the thickness of ice was 9 to 12 inches and 2 to 4 inches of snow had fallen on the surrounding range. He conducted four burns in January and February under the following conditions:

Burn No.	Relative Humidity (%)	Temperature (°F)	Wind (mph)
1	72	30	15
2	60	37	7
3	67	17	23
4	52	42	17

Combustibility of vegetation varied only slightly on all four burns. Density of reed (*Phragmites communis*) and bussrush (*Scirpus* sp.) decreased 85 to 60 percent.

Notice that he conducted successful burns in freezing weather which we cannot do in light or moderate grass fuels. This is primarily because of the large quantity of dry material in thick layers that is partially insulated from the prevailing weather conditions.

Northern Great Plains and Aspen Parkland (low and moderately volatile fuels)

Western snowberry, willows, and dead aspen are volatile fuels and give off abundant firebrands. These firebrands ignite dung piles causing spot fires. This occurs most frequently when the relative humidity is below 40 percent. Consequently, grasslands that have few shrubs or trees are usually comparatively safe to burn.

Snow is an advantage to spring burning programs in mesic areas of the Northern Great Plains. Grasslands melt free from snow several weeks before it has left the adjacent shrublands and forest. Grasslands can then be burned within a few days after snowmelt with the wet forest and shrublands or a plowed line 12 to 14 ft. wide acting as a fireline. Several weeks later the green grassland is an effective fireline when the shrublands and forest are burned.

The weather conditions required for comparatively safe burning in the Alberta aspen parkland are presented in Table 1. The aspen forest and snowberry shrublands have been successfully burned only with headfires. The prescription for grass fires will need to be altered as fine fuel decreases. For example, if you were to burn blue grama, the relative humidity may need to be as low as 25 to 40 percent, wind 8 to 12 mph, and air temperature 50 to 70° F. A few small test burns will help one determine the desired range of weather conditions.

Table 1. Weather Conditions Required for Successful Spring Burning in The Central Alberta Aspen Parkland.

Vegetation Type	Minimum Temperature ° F	Wind Speed mph	Maximum Relative Humidity %	Required Number of Drying Days
Fescue grassland	45	2-12	65	1
Snowberry shrubland	55	2-12	50	4
Aspen forest 1/	59	4-12	40	10
Aspen forest 2/	64	8-12	30	14

1/ There will be few spot fires but only 25 to 50 percent of the forest will be burned if conducted when relative humidity is 30 to 40 percent.

2/ Spot fires will be numerous requiring a 400 foot fireline downwind but 80 to 100 percent of the forest will burn if conducted when relative humidity is 10 to 30 percent.

INTRODUCTION

Grasslands in the semidesert grass-shrub type have gradually given way to higher and higher densities of shrubs during the past 75 year (Fig. 1), but the mechanisms by which the invasion has taken place are not well understood (Buffington and Herbel, 1965; Martin, 1975). The historical role of fire is especially perplexing because fires that kill shrubs usually kill grasses to (Martin, 1975). buffington and herbel (1965) were also skeptical about the role of fire in desert grasslands and did not consider fire as a factor in the maintenance of brush-free range in southern New Mexico. However, Thornber (1907, 1919), Griffiths (1910), Wooton (1916), Leopold (1924), and Humphrey (1958) were convinced that fire controlled shrubs in those portions of the semidesert grass-shrub type that has sufficient fine fuel. "That such fires burning over the mesas and foothills have not been uncomon in times past may be judged by the fact that in many places abundant remains of charred stumps of at least 10 years druation are frequently met with" (Thornber, 1910). Wooton (1916) commented on fires severe enough to kill plants 3.0 to 3.7 m (10 to 12 ft) high.

Despite the skepticism about fire in controlling shrubs in desert gras slands, climate has not changed enough to account for the rapid increase of shurbs (Gardner, 1951; Paulsen, 1956; Humphrey, 1958; Buffington and Herbel, 1965). Moreover, once velvet mesquite (Prosopis glandulosa var. velutina) or honey mesquite (P. glandulosa var. glandulosa) seed-trees were present, mesquite seedlings increased (Griffiths, 1910; Wooton, 1916; Leopold, 1924; Glendening, 1952; Buffington and Herbel, 1965). This leaves the distinct possibility that occasional fires, in combination with drought, competition, rodents, and lagomorphs played a significant role in controlling shrubs in the semidesert grass-shrub type (Griffiths, 1910; Wooton, 1916; Leopold, 1924; Branscomb, 1956; Humphrey, 1958; Bock et al, 1976), except on black grama uplands (Buffington and Herbel, 1965).

RESEARCH SUMMARY

Historical evidence indicates that fires were present in the semidesert grass-shrub type in southereastern Arizona, but there is less supportive evidence for southern New Mexico and southerwestern Texas. The change from grass to brush during the past 80 years was due to a combination of factors related to the intensification of grazing. These factors include: reduction of grass fuel, increased rodent activity, increased erosion that helps cover and irrigate mesquite seed, increased seed dispersal by livestock, increased seed source as more trees came to maturity, and reduction of the competing stands of perennial grasses.

Except for black grama, most grasses in the semidesert grass-shrub type recover from fire in 1 to 3 years. Black grama may take 3 to 8 years to recover, for droughts slow the rate of recovery. If grazing, fire, and droughts are all suppressing black grama simultaneously, it may never fully recover. Drough alone can permanently damage black grama, for the severe drough of 1951 to 1956 on the Jornada Experiment Station, without grazing, reduced black grama on deep sandy and low hummocky sites so severly that it will never recover in our lifetime (Herbel et al, 1972). Forbs are not very abundant, but most seen to be favored by fire.

During dry seasons that follow 1 or 2 previous years of above average summer precipitation, fire can be used to control burroweed, cactus species, broom snakeweed, creosotebush, and young mesquite plants. False-mesquiet, velvet- pod mimosa, Wright baccharis, and fourwing saltbush recover quickly after burning. Wheeler sotol and barrel cactus are severely harmed by fire.

Natural fire frequency was approximated to be 10 years for southeastern Arizona. In southern New Mexico and southwestern Texas, it was probably less than every 10 years, for there is no written record of fire in southern New Mexico (Buffington and Herbel, 1965).

Although fire prescriptions have not been developed for the southern desert grasslands, some general guidelines are recommended where fine fuel exceeds 674 kg/ha (600 lb/acre). These guidelines should be treated as such and used in conjunction with the management implications. Generally, where there are medium or heavy infestations of bruch, there is not enough fine fuel to carry a fire. Research needs are mentioned in the state-of-the-art section.

PRESCRIPTION GUIDES

Prescription guides have not been developed for the semidesert grass-shrub type. Cable (1967) and Dwyer (1972) have reported the conditions under which they burned. Cable conducted burns on areas with 337 to 786 kg/ha (300 to 600 lb/acre) of fine fuel when air temperature was 25° C (77° F), relative humidity was 15 to 18, percent, and wind was 5 to 10 km/hr (3 to 6 mph). In heavier fuel (3,191 to 4,011 kg/ha (2,840 to 3,570 lb/acre), Dwyer (1972) burned when air temperature was 29 to 36° C (85 to 96° F), relative humidity was 5 to 20 percent, and wind was very slight.

Recommendation: Don't try to burn with less than 674 kg/ha (600 lb/acre) of fine fuel unless a good stand of burroweed is present to help carry the fire. Doze a fireline 3.0 to 3.7 m (10 to 12 ft) wide around the area to be burned. About 243 to 1,215 ha (600 to 3,000 acres) would be a reasonable unit to burn. Strip headfire a 30 m (100 ft) strip on the leeward sides of the

planned burning during evening or morning hours in May or June when weather conditions are approximately as follows: aire temperature 21° C (70° F), relative humidity 15-30 percent, and wind less than 13 km/hr (8mph). If the fire continues to back up beyond the 30 m (100 ft) strip, put it out with a pumper. Headfire the remainder of the area when air temperature is 21 to 32° C (70 to 90° F), relative humidity is 10 40 percent, and wind speed is 13 to 24 km/hr (8 to 15 mph).

Quantity of fuel will have a very pronounced effect on fire behavior. Thus, one should do some test burning to approximate the conditions under which fire can be conducted safety and yet accomplish the desired objectives. In heavy fuels such as tobosagress or sacation, a backing fire may be adequate to accomplish objectives. However, where fuel is light (less than 1,000 kg/ha), a wind speed in excess of 13 km/hr (8 mph) will be ncessary for the fire to carry through the fine fuel.

DISTRIBUTION, CLIMATE, SOILS, AND VEGETATION

Distribution

Semidesert grass-shurb vegetation occurs in broad basins, slightly sloping, drainages, and lower slopes of the southern Rocky Mountains in southereastern Arizona, southern New Mexico and southwestern Texas (Fig. 2) (Humphrey, 1958; Martin, 1975; Bunting, 1978). The relatively flat terrain is interrupted by mountain ranges that rise abruptly to elevations of 2,512 to 3,226 m (8,327 to 10,713 ft) (Humphrey, 1958; Martin, 1975; Bunting, 1978). Approximately 17,813,765 ha (44 million acres) occur in the United States, but the center of the semidesert grass-shrub type lies in Mexico (Clements, 1920). Elevation of this vegetation type usually ranges from 915 to 1,372 m (3,000 to 4,500 ft) in Arizona and New Mexico (Martin and Cable, 1974), but occurs as high as 1,740 m (5,707 ft) in southwestern Texas (Bunting, 1978). Below the semidesert shrub-grassland lies the Chihahuan desert and above it the vegetation gives way to chaparral, pinyon-juniper, oak woodland, or occasionally to grassland (Martin, 1975).

Climate

Average annual precipitation ranges from 20 cm (8 inches) at the western edge of Tucson to 51 cm (20 inches) on the lower slopes of mountain ranges in southeastern Arizona and southwestern Texas (Maring, 1975). In south-central New Mexico, average annual rainfall on the Jornada Experimental Range is 23 cm (9.10 inches). Throughout the semidesert grass-shrub region, over 50 percent of the annual rainfall occurs between July 1 and September 30 (Hinkley, 1944; Buffington and Herbel, 1965; Cable, 1972).

Soils

Soils vary widely from sandy or gravelly loams to clays in both the surface and subsoil (Buffington and Herbel, 1965; Cable, 1972). They have developed primarily in alluvium from the adjacent igneous and limestone mountains, are characteristically immature, light colored and low in organic matter (Bunting, 1978). Light precipitation and high evaporation often result in an accumulation of salts in and below the soil in basins. Thus, concentrations of $CaCO_4.2H_2O$ (gypsum) and $CaCO_3$ (lime) occur in many soils throughout the region (Carter and Cory, 1930).

Mesa and upland soils of the black grama community are compacted sands, shallow, and usually are 30 cm (12 inches) or less in depth. Frequently they are underlain by caliche (Nelson, 1934; Martin, 1975). Mixed grama (*Bouteloua* sp.) occurs on a wide variety of soils (Martin, 1975), and mesquite grassland occurs mainly on sandy soils (Buffington and Herbel, 1965). Creosotebush (*Larrea tridentata*) grows best on limestone-derived alluvial fans (Fosberg, 1940) and is absent on soils having gypsum in the profile (Waterfall, 1946; Buffington and Herbel, 1965). Tarbush (*Flourensia cernua*) also grows on limestone-derived soils but predominates on deep well-drained soils (Buffington and Herbel, 1965). Clay soils and fine silts, generally in swales and basins, are deep to moderately deep, poorly drained, calcareous, and contain appreciable quantities of readily soluble salts. They usually support tobosagrass (*Hilaria mutica*) and/or one of the sacaton species (*Sporobolus airoides*, *S. wrightii*) (Buffington and Herbel, 1965; Bock and Bock, 1978).

Vegetation

Major vegetational communities include the black grama uplands (Fig. 3) of New Mexico and west Texas, the flood plains of tobosagrass (Fig. 4), sacaton (*Sporobolus wrightii*) (Fig. 5), or alkali sacaton (*S. airoides*) that occur along water courses, mixed grama (*B. gracilis*, *B. hirsuta*, *B. chondrosioides*) grasslands, mesquite-infested grasslands, the widespread creosotebush stands, and the tarbush, whitethorn (*Acacia constricta*), and creosotebush areas of adjoining and included portions of the Chihuahuan desert (Martin, 1975).

Black grama and tobosagrass are the most common grasses in the semidesert shrub-grassland (Paulsen and Ares, 1962). A rothrock grama (*Bouteloua rothrockii*) community is abundant in Arizona and a curly mesquite (*Hilaria belangeri*) community is scattered throughout the desert grassland on well-drained clay soils (Shantz and Zon, 1924; Humphrey, 1953). Other species in Arizona include annual needle grama (*B. aristidoides*), annual sixweeks threeawn (*Aristida adscenionis*), tall threeawns (*A. hamulosa* and *A. ternipes*), Santa Rita threeawn (*A. glabrata*), bush muhly (*Muhlenbergia porteri*), Arizona cotton-top (*Trichachne californica*), tanglehead (*Heteropogon contortus*), hairy

grama (B. hirsuta), sideoats grama (B. curtipendula), and plains lovegrass (Eragrostis intermedia). Principal plant species in New Mexico on well-drained sites include black grama, mesa dropseed (Sporobolus flexuosus), threeawns (Aristida sp.) and fluffgrass (Erioneuron pulchellum). Low-lying areas contain tobosagrass and burrograss (Scleropogon brevifolius) (Buffington and Herbel, 1965). In Texas, blue grama (B. gracilis), sideoats grama (B. curtipendula), vinemesquite (Panicum obtusum), warnock grama (B. warnockii), bush muhly, dropseed (Sporobolus sp.), hairy tridens (Erioneuron pilosum), and Wooton threeawn (Aristida pansa) may be added to the predominant stands of black grama, alkali sacaton, and tobosagrass (Bunting, 1978). Lehmann lovegrass (Eragrostis lehmanniana) and Boer lovegrass (Eragrostis chloromelas) are the most commonly seeded grasses in the semidesert type (Martin, 1975). Forbs are not very prevalent (Bunting, 1978).

Common shrubs include mesquite, creosotebush, tarbush, fourwing saltbush (Atriplex canescens), soapweed (Yucca elata), and broom snakeweed (Xanthocephalum sarothrae) (Buffington and Herbel, 1965; Martin, 1975). Burroweed (Aplopappus tenuisectus) is prevalent in southern Arizona and southwestern New Mexico, and some acacias (Acacia sp.) may be found throughout the entire region (Martin, 1975). Cane cholla (Opuntia spinosior), jumping cholla (O. fulgida), and Englemann's pricklypear (O. engelmannii) are common cactus species (Cable, 1972).

Herbage Yields

Herbage yields are quite variable. Martin (1965) found that herbage yields ranged from 5.6 to 281 kg/ha (5 to 250 lb/acre) on a mesquite-infested range that received 25 to 30 cm (10 to 12 inches) of precipitation annually. In a higher annual rainfall area (41 cm (16 inches)) yields ranged from 337 to 1,348 kg/ha (300 to 1,200 lb/acre) under a scattered stand of mesquite. In another case on the Santa Rita Experimental Range where precipitation averaged from 19 cm (7.4 inches) in the driest pasture to 27 cm (10.8 inches) in the wettest pasture yields ranged from 19 to 560 kg/ha (17 to 498 lb/acre) (Martin, 1975). On the Jornada Experimental Range where precipitation averages 23 cm (9.1 inches) annually, Herbel (cited by Martin, 1975) reported yields as high as 899 kg/ha (800 lb/acre) on black grama upland sites and 3,933 kg/ha (3,500 lb/acre) on tobosa-alkali sacaton flood plains.

POSSIBLE ROLE OF FIRE IN SEMIDESERT GRASS-SHRUB TYPE

The environmental and biological factors that may have limited the invasion of shrubs into desert grasslands before the arrival of European man in North America have to be looked at simultaneously to evaluate the possible role of fire. Vigorous perennial grasses compete strongly with mesquite seedlings (Martin, 1975; Wright et al, 1976). Experiments on the Santa Rita Experimental Range showed that 16 times as many mesquite seedlings were established on bare areas as in vigorous stands of perennial grasses (Glendening and Paulsen, 1955). Wright et al (1976)

found similar results in west Texas with no survivors in tobosagrass. Moreover, once established, growth of young mesquite plants is severely restricted in good stands of grass for the author observed a mesquite plant 30 cm (12 inches) tall in black grama grass that had been planted 18 years before the date that the author saw it on the Santa Rita Experimental Station. Thus, competition is a key factor in keeping shrubs suppressed. Moreover, frequent droughts in the semidesert grass-shrub type (Nelson, 1934) were just as hard on young mesquite plants as they were on the grasses (Bogusch, 1952).

Droughts can have devastating effects on black grama (Bouteloua eriopoda), the most prevalent grass species in the semidesert grassland (Cottle, 1931; Nelson, 1934). However, black grama can recover quickly following protection and a couple of years of less than average to above average precipitation (Cottle, 1931; Nelson, 1934; Cable, 1975). In 2 years, yield increased from 13 to 131 g/m^2 in southwestern Texas (Cottle, 1931) and area of sets increased from 3.0 to 78.5 cm/m^2 in southeastern Arizona (Nelson, 1934). Regrowth is usually slow the first year of rest but accelerates the second year (Cottle, 1931; Nelson, 1934). Therefore, when livestock was not a factor, a very susceptible plant such as black grama could have quickly reestablished itself with new stoloniferous plants and have been competitive with shrubs, if it had good vigor at the time of the catastrophe and was followed by average or better than average precipitation (Cottle, 1931; Nelson, 1934; Cable, 1975). During the severe drought of 1951 to 1956, however, nearly all of the black grama on deep sandy and low hummocky sites was lost in an ungrazed exclosure and will not recover in our lifetime under complete protection (Herbel et al, 1972). On shallow soils that were underlain by caliche, blue grama was much more resistant to the severe drought.

Mesquite seedlings are most prevalent following warm summers and good fall rains (Wright et al, 1976). Since grassland fires usually occurred during dry seasons that followed 1 or 2 years of average to above average precipitation (Wright and Bailey, 1979), a high percentage of young mesquite plants could easily have been killed by fire (Glendening and Paulsen, 1955; Wright et al, 1976). The few surviving black grama plants (Reynolds and Bohning, 1956) on black grama ranges might have recovered quickly, if ungrazed, because they received good summer rains the year before the fire (Cottle, 1931; Cable, 1975). However, findings by Reynolds and Bohning (1956), where moderate grazing was confounded with fire effects, leaves one to doubt whether grazing can be permitted after a burn until black grama is completely recovered. Intervening droughts can lengthen the recovery period for several years (Nelson, 1934; Reynolds and Bohning, 1956).

For those areas that escaped fire, competition from healthy grass would reduce the number of mesquite plants 94 percent (Martin, 1975). Those that survived would be fed on by jackrabbits (Lepus alleni and L. californicus) (Vorhies and Taylor, 1933) and wood rats (Neotoma sp.)

(Wright and Bailey, 1979), especially during dry seasons to meet metabolic moisture needs. In southeastern Arizona, velvet mesquite constituted 36 to 56 percent of all food consumed by jackrabbits (Vorhies and Taylor, 1933). In well-preserved black grama grasslands, there are relatively small numbers of rodents and lagomorphs (Buffington and Herbel, 1965). Thus, competition from grass and feeding by jackrabbits and wood rats appear to have, historically, been major factors that controlled the density and vigor of mesquite in southern desert grasslands.

Frequent droughts, insects, and diseases would also have taken their toll (Bogusch, 1952; Glendening and Paulsen, 1955; Wright and Bailey, 1979). Velvet mesquite seedlings rarely survived the first spring drought on well-grassed sites (Glendening and Paulsen, 1955). Those areas that escaped fire for 10 to 20 years could easily have kept young mesquite suppressed (via biotic and nonbiotic factors) to less than 1.3 cm (0.5 inch) in diameter. A fire at this time would kill 52 percent of such trees (Glendening and Paulsen, 1955) and probably have kept most of them in a nonseed producing state (Humphrey, 1958; Martin, 1975). Thus, several factors interacting together with the help of fire and no grazing by domestic livestock could have kept shrubs, particularly mesquite, out of the semidesert grasslands. Even black grama could have theoretically tolerated occasional fires when grazing was not a factor.

Overgrazing in Arizona, as practiced by forest administrators in the early 1900's to reduce fire hazard and promote the growth of trees (Leopold, 1924), helped to prevent fires and let brush encroach upon the grassland (Griffiths, 1910). Overgrazing on open range in desert grasslands, particularly during droughts, had a similar effect (Chew and Chew, 1965). Griffiths (1910) and Leopold (1924) concluded that, before 1880, the southern desert grasslands produced more grass and fires occurred at approximately 10-year intervals. Initially, fire harmed the grasses, but 10 years was plenty of time for a lusty growth of grass to come back and accumulate the fuel for another fire (Leopold, 1924). The poor seed source, slow establishment, and slow growth rate of shrubs and mesquite trees would have permitted a fire every 10 years to control the shrubs and mesquite trees (Griffiths, 1910). The key seems to be to burn at frequent enough intervals to prevent the production of seed by the shrubs (Humphrey, 1958; Chew and Chew, 1965; Martin, 1975). No seeds are borne by creosotebush (Larrea tridentata) younger than 13 years and significant numbers of fruits appear only after 18 to 20 years of growth (Chew and Chew, 1965). With competition from biotic and nonbiotic factors, mesquite could also take this long to have seed (Humphrey, 1958; Martin, 1975). This reasoning, however, does not seem to apply for southern New Mexico because there is no historical evidence of fire (Buffington and Herbel, 1965).

Today, grazing by domestic livestock is the biggest hinderance to the potential use of fire in semidesert grass-shrub vegetation, especially black grama ranges. Grazing has reduced fine fuel for fires and allowed shrubs to invade (Chew and Chew, 1965; Martin, 1975). Mesquite trees have become well established on former black grama ranges and have further reduced the chance for a site to produce enough fine fuel to carry a fire (Martin, 1975). Fire might be used to prevent reinvasion (Martin, 1975). In most cases, however, a major reclamation program involving brush control and improved grazing systems would be required to reclaim semidesert grass-shrub ranges to grass before fire could be introduced into a management program (Martin, 1975; Wright et al, 1976).

EFFECTS OF FIRE ON VEGETATION

Grasses

Following a 15-year burning study on the Santa Rita Experimental Range, Cable (1967) concluded that fire had no lasting effects, beneficial or detrimental on perennial grass cover. Generally, the detrimental effects of fire on most of the perennial grasses only lasted 1 to 2 years. Annual grasses (predominantly needle grama and six-weeks threeawn), due to the reduction in burroweed, doubled their yields during wet years (average or above average precipitation), but remained the same as the control during dry years (below average precipitation). Humphrey (1949) reported similar results about the response of annual grasses to fire.

Rothrock grama tolerates fire well unless burned during dry years. Reynolds and Bohning (1956) and Cable (1967) found that burning during a dry year caused a 30 percent reduction in rothrock grama. However, it had fully recovered by the end of the second growing season. In an earlier study, Humphrey (1949) found that numbers of rothrock grama plants were more abundant on two different burns near the Santa Rita Experimental Range than on controls 2 years after the burns.

Black grama is harmed most seriously of all the southern desert grasses and is very slow to recover. Following a hot June fire, Cable (1965) found that 90 percent of the black grama plants died. Even during a wet year, black grama only recovered 23 percent of its preburn basal area after the first growing season (Reynolds and Bohning, 1956). Following two subsequent drought years and moderate grazing, basal cover of black grama had increased to 33 percent. However, basal area of black grama dropped to 22 percent of the preburn basal area at the end of the fourth year when precipitation was above average. These data indicate that droughts following fire will lengthen the recovery period for black grama (Nelson, 1934; Reynolds and Bohning, 1956) and, if compounded with moderate grazing, black grama will never recover to its preburn basal area (Canfield, 1939).

Canfield (1939) found that moderate grazing (simulated by clipping plants to a stubble height of 5 cm) in combination with droughts, regardless of frequency or season of harvesting, reduced the yield of black grama to zero. Moderate grazing entirely outweighed the beneficial effects of above average rainfall. The result was deterioration of black grama sites through excessive wind and water erosion. Thus, if black grama ranges are burned, they should be completely rested until after two consecutive years of above average summer precipitation (Nelson, 1934; Cable, 1975). Then, if grazing is resumed, it should be light.

Rooting of stolons of black grama is the primary method of reproduction. Once these stolons are destroyed, forage is lost and the sand mulch is swept away by winter and spring winds (Herbel et al, 1972) unless other grasses can be established on the site. In many cases, other forage does not become established.

Further north, near Flagstaff, Arizona, where the precipitation is higher than southern New Mexico, Jameson (1962) only noticed a 25 percent reduction in black grama by prescribed fires. Even hot summer fires did not show excessive damage. I have observed similar effects in a 38 cm (15 inch) rainfall area in southeastern New Mexico.

Santa Rita threeawn is favored by fire during wet or dry years, but tall threeawns are generally reduced 30 to 50 percent of their original basal cover (Humphrey, 1949; Reynolds and Bohning, 1956; Cable, 1967). During the first growing season after burning, a dry year, Reynolds and Bohning (1956) found that the density of Santa Rita threeawn had increased 34 percent over the control. Following another dry year at the end of the second growing season, the density had doubled. And after the third growing season, a wet year, the density of Santa Rita threeawn had increased 350 percent. Such dramatic increases were not reported by Cable (1967), but it did increase. The reason that Santa Rita threeawn is more tolerant of fire than other threeawns has been explained by Cable (1967). Santa Rita threeawn generally grows in open areas between burroweed plants, whereas the other threeawns generally grow within the burroweed crowns. Thus, the tall threeawns are subjected to more heat and easily harmed by fire, whereas many Santa Rita threeawn plants are not burned. Generally, threeawn species should be easily harmed by fire because their root-shoot region is close to the soil surface.

Arizona cottontop and tanglehead are mildly harmed by fire during dry years but recover quickly during wet years (Reynolds and Bohning, 1956; Cable, 1967). Neither of these species show a gain in production following burning. However, in the southern mixed prairie where the average rainfall is twice as high as in the southern desert grasslands, Arizona cottontop responds very favorably to fire during wet years (Wright et al, 1974). Based on limited data, bush muhly appears to be seriously harmed by fire (Humphrey, 1949).

Tobosagrass, a dominant of the southern desert grasslands in southern New Mexico and southeastern Arizona, is severely harmed by burning during dry years (produces only 30 to 60 percent as much as the control), but will recover fully by the end of the third growing season if normal precipitation follows the dry year (Dwyer, 1972). In the southern mixed prairie, yield of this species increases two to three-fold if the soil is moist at the time of burning (Wright, 1969, 1972). These differences in response to fire between the two vegetation types can be attributed to differences in precipitation.

Alkali sacaton and sacaton communities, which are similar in density, coarseness and structure to tobosagrass, were probably burned more frequently in their natural state than tobosagrass communities (Humphrey, 1962). Records of fire occurrence are extremely rare. Mesquite and acacia have taken over many sacaton communities. Contributing factors have been overgrazing and channel cutting, which eliminates periodic flooding and lowers the water table. Sacaton grasslands require 2 years to fully regain plant cover and 54 percent of its original height (Bock and Bock, 1978). In this community, vine-mesquite was significantly more abundant on a winter burned area than on an unburned area (Bock and Bock, 1978).

On the northern boundary of the semidesert grass-shrub type, Galleta (Hilaria jamesii) is slightly harmed by fire (Jameson, 1962; Dwyer and Pieper, 1967). Following winter burns with adequate soil moisture, galleta yielded 75 percent as much forage the first growing season after burning as the unburned control.

Wolf plants of Lehmann lovegrass, an introduced species, are severely reduced by hot wildfires in June, but seedlings quickly reestablish on the burned areas (Cable, 1965). A burn that was followed by unusually favorable moisture for plant growth reduced a stand of Lehmann lovegrass about one third (Humphrey and Everson, 1951). Seedlings were abundant, however, and the reduction in forage yield was only temporary. Following a February burn, Pase (1971) found that lovegrass in a chaparral community was essentially unaffected by burning. Since this species of lovegrass is a bunchgrass, damage by fire would be related to intensity of the fire, amount of dead fuel in plant crowns, soil moisture, and precipitation that followed the burn.

Forbs

Forbs are generally not mentioned in the literature for semidesert grass-shrub communities, but Bock and Bock (1978) reported that forbs which were more common in sacation communities after winter or summer burning included Amaranthus, Ipomaea, Bidens, Convolvulus, Solidago, Portulaca, Chenopodium, and Ambrosia.

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Grasslands in the semidesert grass-shrub type have gradually given way to higher and higher densities of shrubs during the past 75 years (Fig. 1), but the mechanisms by which the invasion has taken place are not well understood (Buffington and Herbel, 1965; Martin, 1975). The historical role of fire is especially perplexing because fires that kill shrubs usually kill grasses too (Martin, 1975). Buffington and Herbel (1965) were also skeptical about the role of fire in desert grasslands and did not consider fire as a factor in the maintenance of brush-free range in southern New Mexico. However, Thornber (1907, 1919), Griffiths (1910), Wooton (1916), Leopold (1924), and Humphrey (1958) were convinced that fire controlled shrubs in those portions of the semidesert grass-shrub type that had sufficient fine fuel. "That such fires burning over the mesas and foothills have not been uncommon in times past may be judged by the fact that in many places abundant remains of charred stumps of at least 10 years duration are frequently met with" (Thornber, 1910). Wooton (1916) commented on fires severe enough to kill plants 3.0 to 3.7 m (10 to 12 ft) high.

Despite the skepticism about fire in controlling shrubs in desert grasslands, climate has not changed enough to account for the rapid increase of shrubs (Gardner, 1951; Paulsen, 1956; Humphrey, 1958; Buffington and Herbel, 1965). Moreover, once velvet mesquite (*Prosopis glandulosa* var. *velutina*) or honey mesquite (*P. glandulosa* var. *glandulosa*) seed-trees were present, mesquite seedlings increased in Arizona and New Mexico whether pastures were protected or grazed (Griffiths, 1910; Wooton, 1916; Leopold, 1924; Glendening, 1952; Buffington and Herbel, 1965). This leaves the distinct possibility that occasional fires, in combination with drought, competition, rodents, and lagomorphs played a significant role in controlling shrubs in the semidesert grass-shrub type (Griffiths, 1910; Wooton, 1916; Leopold, 1924; Branscomb, 1956; Humphrey, 1958; Bock et al, 1976), except on black grama uplands (Buffington and Herbel, 1965).

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Historical evidence indicates that fires were present in the semi-desert grass-shrub type in southeastern Arizona, but there is less supportive evidence for southern New Mexico and southwestern Texas. The change from grass to brush during the past 80 years was due to a combination of factors related to the intensification of grazing. These factors include: reduction of grass fuel, increased rodent activity, increased erosion that helps cover and irrigate mesquite seed, increased seed dispersal by livestock, increased seed source as more trees came to maturity, and reduction of the competing stands of perennial grasses.

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PRESCRIPTION GUIDES

Prescription guides have not been developed for the semidesert grass-shrub type. Cable (1967) and Dwyer (1972) have reported the conditions under which they burned. Cable conducted burns on areas with 337 to 786 kg/ha (300 to 600 lb/acre) of fine fuel when air temperature was 25° C (77° F), relative humidity was 15 to 18 percent, and wind was 5 to 10 km/hr (3 to 6 mph). In heavier fuel (3,191 to 4,011 kg/ha (2,840 to 3,570 lb/acre), Dwyer (1972) burned when air temperature was 29 to 36° C (85 to 96° F), relative humidity was 5 to 20 percent, and wind was very slight.

Recommendation: Don't try to burn with less than 674 kg/ha (600 lb/acre) of fine fuel unless a good stand of burroweed is present to help carry the fire. Doze a fireline 3.0 to 3.7 m (10 to 12 ft) wide around the area to be burned. About 243 to 1,215 ha (600 to 3,000 acres) would be a reasonable unit to burn. Strip headfire a 30 m

(100 ft) strip on the leeward sides of the planned burning during evening or morning hours in May or June when weather conditions are approximately as follows: air temperature 21° C (70° F), relative humidity 15-30 percent, and wind less than 13 km/hr (8 mph). If the fire continues to back up beyond the 30 m (100 ft) strip, put it out with a pumper. Headfire the remainder of the area when air temperature is 21 to 32° C (70 to 90° F), relative humidity is 10 to 40 percent, and wind speed is 13 to 24 km/hr (8 to 15 mph).

Quantity of fuel will have a very pronounced effect on fire behavior. Thus, one should do some test burning to approximate the conditions under which fire can be conducted safely and yet accomplish the desired objectives. In heavy fuels such as tobosagrass or sacaton, a backing fire may be adequate to accomplish objectives. However, where fuel is light (less than 1,000 kg/ha), a wind speed in excess of 13 km/hr (8 mph) will be necessary for the fire to carry through the fine fuel.

DISTRIBUTION, CLIMATE, SOILS, AND VEGETATION

Distribution

Semidesert grass-shrub vegetation occurs in broad basins, slightly sloping drainages, and lower slopes of the southern Rocky Mountains in southeastern Arizona, southern New Mexico and southwestern Texas (Fig. 2) (Humphrey, 1958; Martin, 1975; Bunting, 1978). The relatively flat terrain is interrupted by mountain ranges that rise abruptly to elevations of 2,512 to 3,266 m (8,239 to 10,713 ft) (Humphrey, 1958; Martin, 1975; Bunting, 1978). Approximately 17,813,765 ha (44 million acres) occur in the United States, but the center of the semidesert grass-shrub type lies in Mexico (Clements, 1920). Elevation of this vegetation type usually ranges from 915 to 1,372 m (3,000 to 4,500 ft) in Arizona and New Mexico (Martin and Cable, 1974), but occurs as high as 1,740 m (5,707 ft) in southwestern Texas (Bunting, 1978). Below the semidesert shrub-grassland lies the Chihuahuan desert and above it the vegetation gives way to chaparral, pinyon-juniper, oak woodland, or occasionally to grassland (Martin, 1975).

Climate

Average annual precipitation ranges from 20 cm (8 inches) at the western edge of Tucson to 51 cm (20 inches) on the lower slopes of mountain ranges in southeastern Arizona and southwestern Texas (Martin, 1975). In south-central New Mexico, average annual rainfall on the Jornada Experimental Range is 23 cm (9.10 inches). Throughout the semidesert grass-shrub region, over 50 percent of the annual rainfall occurs between July 1 and September 30 (Hinkley, 1944; Buffington and Herbel, 1965; Cable, 1972).

Cacti

Cactus species are relatively susceptible to fire. Using data from three studies--Humphrey (1949), Reynolds and Bohning (1956), and Cable (1967)--average kills two growing seasons after a burn for jumping cholla, cane cholla, pricklypear, and barrel cactus (Echinocactus wislizenii) were about 50, 45, 30, and 65 percent, respectively. These mortalities usually included the interactive effects between fire, insects, drought, and grazing by rodents, lagomorphs and domestic animals. For example, when the spines of barrel cactus are burned off, cattle eat them readily (Reynolds and Bohning, 1956).

Cane cholla and pricklypear do not recover from the effect of initial burns for at least 13 years after a burn (Cable, 1967). However, jumping cholla increased 17 percent 13 years after a burn. Reburns that were 3 years apart did not increase the mortality of cactus species (Cable, 1967). The reason given was that the first burn removed the accumulated weeds and litter from the base of cactus plants.

A study by Glendening (1952) also supports the need for fire to control cactus species. His 17-year study showed that cane cholla, pricklypear, and barrel cactus increased under protection and under moderate grazing. Jumping cholla was the only species that decreased under protection. However, it appears that jumping cholla has a life span of about 40 years and may go through rapid die-off cycles due to population build-ups of bacillus (Edwinea carnegieana) (Tschirley and Wagle, 1964; Martin and Turner, 1977). Die-offs of 25 to 35 percent also occur in the other cactus species from time to time (Humphrey and Everson, 1951). The important point is that, as yet, there is no evidence to support the common belief that reduced grass competition, resulting from grazing, has caused cactus species to flourish. More likely, lack of fire has caused them to flourish, as the evidence seems to suggest.

Shrubs

Griffiths (1910) and Wooton (1916) believed that fires almost entirely prevented the establishment of undesirable shrubs in the southern desert. Griffiths stated that, because of the slow growth of shrubs, he believed they could be controlled by fires that occurred only once in 10 years. Wooton (1916) working in the same area (Santa Rita Experimental Range, Arizona) saw occasional fires that were hot enough to kill mesquite trees 3.0 to 3.7 m (10 to 12 ft) high. In his opinion, fire had been the only restricting influence on the spread of trees and shrubs. Although grasses, with the possible exception of black grama, recovered quickly from such burning, shrubs were usually just reappearing by the time another fire occurred. Regrowth from small mesquites that are merely top-killed can be rapid, however.

One of the most prevalent shrub-tree species in the Southwest is velvet mesquite. This species is moderately affected by fire, depending on the size of mesquite and amount of fine fuel available for burning (Cable, 1961, 1965, 1967; White, 1969). Following a wildfire on June 28, 1963, Cable (1965) reported a 21 percent kill of mesquite less than 5 cm (2 inches) in diameter and a 10 percent kill of trees larger than 5 cm (2 inches) in diameter. Using artificial fuels for controlled fires, Glendening and Paulsen (1955) obtained a 52 percent kill on young mesquites having basal stem diameters of 1.3 cm (0.5 inches) or less. Only 8 to 18 percent of the larger trees were killed by fire. Reynolds and Bohning (1956) killed 9 percent of the mesquite trees by using a prescribed burn on June 30, 1952. In a wildfire near Sasabe, Arizona, White (1969) reported a 20 percent kill of mesquite trees in moderate and severe burns.

Occasionally, fire may be more damaging to mesquite than is normally expected. Humphrey (1949) has reported mesquite kills of 50 percent on the Beach Ranch Study and 75 percent on the Sierrita Mountain Study. After 15 years, Humphrey revisited these same areas and still found mesquite drastically reduced. High kills such as these reported by Humphrey are rare. Part of this variation in mesquite kills, however, may be due to the amount of fuel available. On areas having 5,056 kg/ha (4,500 lb/acre) of fine fuel, fire killed 25 percent of the mesquites, but on areas having 2,472 kg/ha (2,200 lb/acre) of fine fuel, only 8 percent of the mesquites were killed (Cable, 1965). Another source of variation is the general vigor of the plants. Mesquite plants with low vigor, growing on dense rocky subsoils, do not have the recovery potential that more vigorous trees do. Another factor may be the degree to which erosion has removed soil around the base of the tree thereby exposing the bud zone to heat. Lastly, summer burns are more damaging to mesquite than winter burns (Glendening and Paulsen, 1955; Blydenstein, 1957).

In addition to the mortality of plants, burning in some way seems to inhibit the establishment of mesquite seedlings. Mesquite numbers on an unburned area increased from 40 to 128/ha (from 16 to 52/acre) within a 13-year period while they only increased from 59 to 62/ha (from 24 to 25/acre) on a burned area (Cable, 1967). Reduced yield of mesquite seed on trees that were partially top-killed may be one reason for such an effect. The reduction in numbers of Merriam kangaroo rats (Dipodomys merriamai), resulting from the loss of cactus and other shrubs that formerly sheltered the rats, would also reduce the amount of seed cached on a burned area. Lastly, jackrabbits eat young mesquite plants (Vorhies and Taylor, 1933), and the mortality of mesquite seedlings is higher on areas grazed by cattle and jackrabbits than in cattle-jackrabbit exclosures (Glendening, 1952).

Generally speaking, velvet mesquite in southeastern Arizona is more susceptible to fire than honey mesquite which grows in New Mexico and Texas. Two successive fires are necessary to kill 27 percent of

the large honey mesquite trees on upland sites in the Rolling Plains of Texas, but trees are rarely killed with successive fires on bottomland sites (Wright et al, 1976). Seedlings of honey mesquite are easy to kill with moderate fires until they reach 1.5 years of age, severely harmed at 2.5 years of age, and very tolerant of intense fires after 3.5 years of age (Wright et al, 1976). At these young ages, velvet mesquite might be slightly more tolerant of fire based on data by Cable (1961) but his seedlings had been transplanted when 3 or 4 weeks old. On the High Plains (shortgrass prairie) of Texas, where mesquite was not reported by early scouts, honey mesquite is very tolerant to fire. We have observed no mortality, indicating that the plants have evolved in a fire environment and were kept suppressed by fire, droughts, competition, rodents and lagomorphs (Wright et al, 1976).

Other shrubs, only moderately affected by fire, are false-mesquite (Calliandra eriophylla) and velvet-pod mimosa (Mimosa dysocarpa). Very few of these plants (2-10 percent) died on severe burns and no plants died on light and moderate burns (White, 1969). Reynolds and Bohning (1956) found that false-mesquite recovered within 2 years after burning and had almost doubled its crown density compared to unburned areas by the third year after burning.

Soapweed can be adversely affected by fire. Humphrey (1949) reported a 25 percent kill following a wildfire on Sierrita Mountain. In general, however, most Yucca species are tolerant of fires and appear to hold their position in various plant communities despite fire.

Ocotillo (Fouquieria splendens) and Wheeler sotol (Dasylirion wheeleri) are severely reduced by fire (White, 1969). In a June, 1963, wildfire, many plants of ocotillo died--67 percent in severe burns, 40 percent in moderate burns, and 50 percent in light burns. Only 3 percent of the Wheeler sotol plants survived severe burns, but all survived in moderate and light burns.

Larchleaf goldenweed (Aplopappus laricifolius) is also easily killed by fire (White, 1969). Severely damaged plants were completely killed and did not sprout by the end of the second growing season. Only 10 percent of the moderately damaged plants survived following fire. About 90 percent of the lightly damaged plants survived in the first growing season, but the number of survivors declined to 80 percent in the second growing season.

Paloverde (Cercidium floridum), broom snakeweed, and burroweed are three more species that can be severely damaged by fire. Humphrey (1949) reported a 90 percent mortality of paloverde on the Sierrita Mountain Study. Wooton (1916) observed that broom snakeweed was easily killed by fire. A later study showed that mortalities of broom snakeweed and burroweed following a July control burn were 95 percent or higher (Humphrey and Everson, 1951). Cable (1967) and

Reynolds and Bohning (1956) have also reported 95 to 100 percent kills for burroweed, when burned in June. One study on burroweed in which burning was done at all seasons of the year showed burning to be reasonably effective from mid-April to mid-September, but most effective about June 1 (Tschirley and Martin, 1961).

After 6 years, Cable (1967) found that burroweed was only 25 to 30 percent of preburn density on a June burn (Fig. 6), although it fluctuated upward during wet years and downward during dry years. After 4 years, burroweed exceeded preburn densities (Fig. 6). However, in another study, Humphrey (1949) found that burroweed failed to re-invade after 15 years following a wildfire. The most striking effect of June burns in southern desert grasslands is the elimination of burroweed, at least temporarily, and the increase in annual grasses during wet years (Cable, 1967).

Thornber (1907) noted that fire was effective in killing catclaw (Acacia greggii), creosotebush, Mormon tea (Ephedra trifurca), and graythorn (Condalia lycioides). Except for creosotebush, however, no research studies document the extent to which these species are affected by fire. Creosotebush (Fig. 7) can resprout after burning, but intense fires, particularly during June, will cause 100 percent mortality (White, 1968; White and Ehrenreich, 1968).

Algerita (Berberis trifoliata), fourwing saltbush, winterfat (Eurotia lanata), and skunkbush sumac (Rhus trilobata) resprout vigorously after fire (Dwyer and Pieper, 1967). Wright baccharis (Baccharis wrightii), a highly palatable shrub, also resprouts vigorously and appears to be unaffected by fire (Humphrey, 1949).

Desert blackbrush (Coleogyne ramosissima) (Fig. 8), a nonsprouter in northern Arizona and southern Nevada and Utah (a transitional zone of vegetation between the salt desert shrub and the semidesert grass-shrub types), is very susceptible to fire and is slow to re-invade after fires in southern Nevada and Utah (Jenson et al, 1960; Beatley, 1966). Plant communities that succeed blackbrush are highly variable (Bowns and West, 1978). Bowns and West found that some plant communities will return to a mixture of shrubs, such as turpentine bush (Thamnosma montana), desert bitterbrush (Purshia glandulosa), desert almond (Prunus fasciculata), and big sagebrush (Artemisia tridentata). Other areas return to pure stands of snakeweed (Xanthocephalum microcephala) or big sagebrush. Even though desert blackbrush is not a preferred shrub, widescale burning is not recommended as a desirable management policy for this type (Bowns and West, 1978). The vegetation that may follow is too unpredictable.

MANAGEMENT IMPLICATIONS

The southern desert grass-shrub type is a delicate ecosystem with side swings in herbage yields because severe droughts are common. Moreover, droughts frequently last 2 or 3 years. When moderate to heavy grazing is superimposed on black grama ranges, grass competition and vigor of grasses are drastically reduced (Canfield, 1939). These factors favor high mortality of herbs during drought years and the eventual establishment of shrubs following wet years when other climatic factors, such as soil temperature, are favorable. It appears that use of fire would compound the existing problems on black grama ranges and may not have a place for shrub control on good ranges.

Our problem is to reclaim poor rangelands (predominately brush) and to properly manage our good rangelands. Poor rangelands cannot be managed with fire. These rangelands must first be restored using other reclamation techniques. However, once the rangelands are in good condition, fire can be used as an effective management tool in special situations during wet weather cycles to control burroweed, broom snakeweed, creosotebush, and young mesquite trees. Fires can also be used to suppress cactus species. Most burning should be done in June, but only following 2 previous years of better than average plant growth. This is especially important for grasses to recover quickly after burning.

Desirable shrubs that are either favored or not harmed by fire include false-mesquite, velvet-pod mimosa, Wright baccharis, and four-wing saltbush. Wheeler sotol and barrel cactus are easily harmed by fire and should be protected, if possible.

Today, fire should be used only on a selective basis, or in combination with other methods, to achieve specific management objectives in the semidesert grass-shrub type. Fire probably has the greatest value to manage tobosagrass, sacaton, alkali sacaton, and mixed grama ranges. Good black grama grasslands appear to be too delicate to manage with fire. If fire is used, 3 to 4 years' rest might be required after the burn.

STATE-OF-THE-ART

Considerable fire research has been done in the semidesert grass-shrub type, but most observations and research have been concentrated in southeastern Arizona. In southern New Mexico, a drier climate, relatively little fire research has been attempted because it was never thought to have played a very important role in the maintenance of southern desert grasslands (Buffington and Herbel, 1965). Moreover, now that honey mesquite has invaded many of the sandy sites, fire has no value to restore the sites to black grama grasslands because there is not enough fine fuel to carry a fire.

Since black grama, which is intolerant of fire, was such an important grass in southern desert grasslands over the entire region, long-term research is needed to determine whether fire every 10 years or less frequently could have kept mesquite suppressed. Maybe fire never played a significant role in black grama grasslands, but this question needs to be answered. The following specific questions need to be answered. In what kind of years do mesquite seedlings germinate and become established? How rapidly do these young trees grow under different degrees of grass competition? How easily are specific ages of trees killed? How does the interaction of age of mesquite tree, grass competition, drought, fire and rabbits affect mesquite growth and seed production?

Cover of black grama fluctuates widely with droughts (Nelson, 1934), and most of our fire effects data is confounded with drought and grazing. Fire effects need to be evaluated alone and in combination with drought and grazing. This is important to determine how much fire, drought, and grazing black grama can tolerate. Based on Canfield's (1939) clipping research, light grazing should be the severest grazing treatment used with fire on black grama ranges, if fire can be used at all.

Jackrabbits appear to have been a significant factor in keeping young mesquite trees suppressed in healthy stands of grass (Humphrey, 1958). Thus, the preferred diet balance of jackrabbits and their interaction with other environmental factors in good stands of grass should be carefully studied.

Forb data is minimal in the literature. This is because they are insignificant when total herbaceous yield is considered. However, since we have to be concerned about the total ecosystem, we need better data on forb species to evaluate the impact of our management systems on wildlife. Many wildlife species only need a small amount of specific forb species to exist in certain habitats.

Table 1. Summary of fire effects on major grass species.

Species	Response to fire	Recovery time	Remarks
Alkali sacaton) Sacaton)	Tolerant	2-4 years	Basal area recovers in 2 years, but only 54% of height recovers in 2 years.
Annual grasses			
Needle grama) Six-weeks threeawn)	Favored	1 year	Double their yields the first growing season after burning with average or better than average precipitation. Yields remain the same if precipitation is below average.
Arizona cottontop	Tolerant	1-3 years	Cover or yields may be reduced 40% if precipitation is below average, but recovers the first year if precipitation is average or better.
Black grama	Not tolerant	3-8 years	Basal area of black grama is reduced 90% by hot June fires and remains reduced 78% at the end of the first growing season when precipitation is above average. It may need 3 or 4 years' rest after a burn before light grazing can be resumed.
Bush muhly	Not tolerant	Unknown	Observations based on very limited data (Humphrey, 1949).
Galleta	Tolerant	2 years	Recovers 75% of its original growth the first year after a burn.
Lehmann lovegrass	Tolerant	1-2 years	Large bunchgrasses can be severely damaged, but seedlings of this species quickly reestablish on the burned area.
Rothrock grama	Favored	1-2 years	May be reduced as much as 30% at the end of the first growing season, but recovers fully with average or better than average summer precipitation.
Tall threeawns	Moderately tolerant	2-3 years	Original basal cover is generally reduced 30 to 50%.
Tanglehead	Tolerant	1-3 years	Same as for Arizona cottontop.
Tobosagrass	Tolerant	1-3 years	Yields can be reduced 40 to 70% if burned during dry years, but will hold its own if summer precipitation after the burn is average.

Table 2. Summary of fire effects on forb and cactus species.

Species	Response to fire	Recovery time	Remarks
Forbs			
<u>Amaranthus</u>) <u>Ambrosia</u>) <u>Chenopodium</u>) <u>Convolvulus</u>) <u>Ipomaea</u>) <u>Portulaca</u>) <u>Solidago</u>)	Favored	1 year	Cover of a mixture of these forbs increased 60% above the control at the end of the first growing season in southeastern Arizona and remained at this level at the end of the second year after burning.
Cacti			
Barrel cactus	Not tolerant	> 15 years	Reduced 65% after burning.
Cane cholla	Moderately tolerant	15 years	Reduced 45% after burning.
Jumping cholla	Moderately tolerant	10 years	Reduced 50% after burning.
Pricklypear	Moderately tolerant	15 years	Reduced 30% after burning.

Table 3. Summary of fire effects on shrub species.

Species	Response to fire	Recovery time	Remarks
Algerita	Tolerant	10-15 years	Vigorous sprouter.
Blackbrush	Not tolerant	> 28 years	Nonsprouter. Seedlings reestablish on burned areas very slowly.
Broom snakeweed	Not tolerant	5-10 years	95% mortality, but reestablishes itself with seedlings following wet winters and springs.
Burroweed	Not tolerant	10-20 years	Mortality is 95 to 100%. After 6 years, 25 to 30% of the preburn density has recovered. After 13 years, burroweed exceeded preburn densities in one study but had failed to reinvade in another. However, if burns are followed by wet winter-spring periods, new stands can become reestablished rather quickly.
Catclaw	Tolerant	10-15 years	Vigorous sprouter.
Creosotebush	Not tolerant	Unknown	Very susceptible to hot June fires, but some resprouting takes place when burned during other months of the year. A weak sprouter.
False-mesquite	Very tolerant	2 years	Fully recovers by second year after burning and almost doubles by third year after burning.
Fourwing saltbush	Tolerant	2-3 years	Vigorous sprouter.
Graythorn	Harmed	Unknown	Can be killed by fire (Thornber, 1907), but no research studies have been conducted on this species.
Honey mesquite) Velvet mesquite)	Tolerant	20-30 years	Young plants are easily killed, but both species are vigorous sprouters. On upland sites, two successive burns can kill 27% of the large trees, but on bottomland sites, mesquite is very tolerant to fire. Large trees of velvet mesquite appear to be more susceptible to fire than honey mesquite.
Mormon tea	Harmed	Unknown	Based on limited observations by Thornber (1907).
Larchleaf goldenweed	Not tolerant	Unknown	90% of the plants will be killed by hot fires and 20% will be killed by light fires.

Table 3 (Continued). Summary of fire effects on shrub species.

Species	Response to fire	Recovery time	Remarks
Ocotillo	Not tolerant	Unknown	67% died in severe burns, 40% in moderate burns, and 50% in light burns.
Paloverde	Not tolerant	Unknown	Humphrey (1949) reported a 90% mortality following a wildfire.
Skunkbush sumac	Tolerant	10-15 years	Vigorous sprouter.
Velvet-pod mimosa	Very tolerant	Unknown	Very few plants died on severe burns and no plants died on light and moderate burns.
Wheeler sotol	Not tolerant	Unknown	97% of the plants died in severe burns, but all plants survived in light and moderate burns.
Winterfat	Tolerant	2-3 years	Vigorous sprouter.
Wright baccharis	Tolerant	Unknown	Appears to be unaffected by fire (Humphrey, 1949).
Yucca	Tolerant	2-5 years	Very hot fires may cause 25% mortality, but generally few plants die following fire.

INTRODUCTION

Historical evidence indicates that fires have always been an ecological force in ponderosa pine (Pinus ponderosa) communities, regardless of whether they were seral or climax (Dutton 1887, Daubenmire 1943, Arnold 1950, Weaver 1951a, 1951b, 1959, Cooper 1960, Biswell 1963, 1967, Gartner and Thompson 1972, Van Wagtendonk 1974, Hall 1976). These fires thinned the stands, eliminated young pines and/or climax mixed-conifer species including thickets, and kept the ponderosa pine forests open and park-like with an undersotry of herbs and shrubs (Arnold 1950, Beale 1958, Weaver 1947, 1951a, 1967b, Cooper 1960, Gartner and Thompson 1972, Biswell 1972, Progulske 1974, Hall 1976). Only in the Sierra-Nevada mixed-conifer type were there relatively few grasses and shrubs in the understory, but the forest was more open with fewer incense cedar (Libocedrus decurrens) and white fir (Abies concolor) thickets (Van Wagtendonk 1974). The forest floor was carpeted with needles, bear clover (Chamaebatia foliolosa), and some forbs and grasses (Van Wagtendonk 1974).

Successful prescribed burns not only have shown the potential to thin stands of ponderosa pine, allow crop trees to increase in diameter, eliminate thickets (Weaver 1967a), and increase forage yields (Cooper 1960, Biswell 1972, Hall 1976, Severson and Boldt 1977), but also to reduce wildfire hazards for 5 to 7 years (Truesdell 1969). The ability of ponderosa pine to survive severe wildfires following natural fires at 5 to 10-year frequencies has been confirmed in Arizona by an 80,000-acre wildfire in 1903-1904 (Kallander 1969) and by a 57,000-acre wildfire in 1971 (Wagle and Eakle 1977). On these burns few trees were killed that had a recent fire history, but on untreated areas the fire destroyed everything in its path, except for those burns which occurred during late evening and early morning when the fires were cool (Wagle and Eakly 1977).

Truesdell (1969) reported that no fire larger than 10 acres (4 ha) in size had ever occurred in ponderosa pine on the Fort Apache Reservation within 7 years following a controlled burn. Knorr (1963), working in the same area, made a special study that showed wildfires were only 1/14 as large as fires on untreated areas. For three fire seasons following controlled burning of 65,000 acres (26,316 ha) on the Fort Apache Reservation, Kallander et al. (1955) showed an 82 percent reduction in the number of wildfires, a 94 percent reduction in area burned, and a 65 percent reduction in the average size of a fire. Similarly, on the Colville Indian Reservation in Washington, Weaver (1957) showed a 90 percent reduction in the number of acres burned, a 94 percent reduction in damage, and a 79 percent reduction in the cost of control per wildfire on previously burned communities. To maintain such low fire hazards, Biswell et al. (1973) recommended burning ponderosa pine communities every 5 to 7 years. Where fuel build-ups are high, several successive burns of low intensity must occur to reduce the surface fuels to acceptable levels (Weaver 1957, Biswell 1963, Van Wagtendonk 1974), if it can be done at all (Gordon 1967).

On the other hand, prescribed fires have killed quality ponderosa pine trees on the Fort Apache Indian Reservation in eastern Arizona, especially where crown fires occurred (Lindenmuth 1960). Light surface fires, hot surface fires, and crown fires killed 0.8, 9.2, and 47.3% of the potential crop trees in the 4- to 7-inch (10- to 18-cm) d.b.h. class. The same fires killed 21.3, 57.5, and 73.7% of the trees in the 0 to 4.5 ft (0 to 1.4 m) height class, respectively. Thus, it appears that, depending on one's objectives, prescribed burns have the potential to clean out understories of potential crop trees and to thin stands of ponderosa pine if fire prescriptions are written on a unit-objective basis. True, some losses of wood products will occur and the thinning will not be uniform (Wooldridge and Weaver 1965), but if weighed against the benefits of fuel reduction and the potential for a variety of uses that are compatible with the carrying capacity of the land, the loss of wood products may be justified (Meyers 1974).

Most managers have preferred to protect their forests from intentional fires because they have deep feelings of wariness and uncertainty as to whether fire can be used safely and effectively. There is too much evidence of some really impressive conflagrations in "pristine" forests--especially ponderosa pine--to believe that hot fires did not also play a major role along with the gentle burns which undoubtedly occurred (C. E. Boldt, Silviculturist, Rapid City, South Dakota, Pers. Comm.). Thus, most managers are uneasy about potential "benefits" of using prescribed fire to reduce fuel build-ups and to precommercially thin forests. The net result has been a high incidence of crown fires and overstocked stands on poor sites that grow slowly and are too expensive to thin by hand (Weaver 1943, Biswell et al. 1973, Hall 1976).

Managers realize the strong tendency of overstocked ponderosa pine stands to stagnate (Biswell et al. 1973, Meyers 1974, Hall 1976). The need for precommercial thinning and release of stagnant trees is common knowledge. The real problem is that most managers have not been convinced that they can safely substitute fire for conventional thinning. There have been few studies to document the burning prescriptions for results such as those claimed by Weaver (1947) and Biswell et al. (1973). Moreover, there have been few economic studies such as the one by Clary et al. (1975) to show how we should manage ponderosa pine communities when we consider all of the resources.

This paper gives a state-of-the-art review on the use and effects of fire, management implications, and research needs for six regions of the country where ponderosa pine grows.

FIRE HISTORY

Frequency of natural fires in ponderosa pine varied considerably depending on the regional area and site. In Arizona and New Mexico the frequency for climax and seral communities of ponderosa pine was between 4.8 and 11.9 years (Weaver 1951a). Show and Kotok (1924) and Wagener (1961) found that it was 8 to 10 years for seral communities of ponderosa pine in California, as did Hall (1976) for seral ponderosa pine in the Blue Mountains of eastern Oregon. Weaver (1959, 1967a), working with a wide range of climax and seral ponderosa pine community types in eastern Washington, showed that fire frequency varied form 6 to 47 years.

In the Bitterroot National Forest of eastern Idaho and western Montana fire frequency averaged from 6 to 11 years (range 2 to 20 years) for climax ponderosa pine and 7 to 19 years (range 2 to 48 years) for ponderosa pine that was seral to Douglas fir (Pseudotsuga menziesii) (Arno 1976). Eastward in South Dakota, historical documents from 1874 to 1880 show that lightning fires were prevalent in the Black Hills of South Dakota (Gartner and Thompson 1972). Photographs taken in 1874 and again in 1974 (Progulske 1974) confirm the significant role of fire, and Progulske estimated the fire frequency to be 15 to 20 years. Hendrickson (1972) estimated the fire frequency in Colorado and Wyoming to be 12 to 25 years. In this area there are many poor, dry sites where litter build-up is slow and the grass understory is thin.

RESEARCH SUMMARY

Fires have always been an ecological force in ponderosa pine communities, regardless of whether they were seral or climax. Average fire frequency varied from 6 to 19 years with a range of 2 to 48 years. The most important function of natural fires may have been to create a potential for a variety of uses that were compatible with the carrying capacity of the land.

Prescribed fires at 5- to 7-year intervals reduce the acreage burned in wildfires by 90 percent, but some potential crop trees may be lost. Nevertheless, prescribed fires show the potential to effectively reduce fuel build-ups and thin trees if the prescription can be developed and applied on a unit-objective basis. The loss in wood products may be offset by gains in other multiple use objectives.

Distribution, climate, elevation, soils and the general succession pattern of ponderosa pine after fires are discussed for the ponderosa pine type. Vegetation and fire effects are presented for six specific habitat types. Fire is generally beneficial to herbs and shrubs because it removes needle mats and understory pine trees. Forage yields vary from 843 to 1,910 hg/ha in openings and as low as 56 kg/ha under 70 to 100 percent canopies. Open stands of ponderosa pine contain from 281 to 674 kg/ha of forage in climax and seral communities.

Most grasses recover in 1 to 3 years after fire. Except for antelope bitterbrush, the shrubs are very tolerant of fire. Most are vigorous sprouters and many come back from seed after fire. However, there is a lack of specific data for many plant species within each of the ponderosa pine habitat types.

Except for clearcutting, most harvesting methods are highly satisfactory for regenerating ponderosa pine, but competition from grasses and shrubs as well as the use of prescribed fire may be necessary to prevent overstocking. Fuel build-ups and stagnation are two of the most serious management problems in ponderosa pine communities. It appears that fire has the potential to be used as a safe and economical tool to manage such stands, but specific guidelines are only now being developed and tested. Lastly, fires are not equally desirable or necessary in all ponderosa pine communities.

DESCRIPTION OF PONDEROSA PINE SITES

Distribution

Ponderosa pine is widely distributed, both as a climax and seral species. It spans a north-south distance (southern British Columbia to Durango, Mexico) of 2,300 miles (3,710 km) and an east-west distance (California to north-central Nebraska) of 1,260 miles (2,032 km). Climax communities include the Interior Ponderosa Pine and Pacific Ponderosa Pine Types (Fowells 1965). They are usually characterized by shrubby or grassy understories (Daubenmire 1969). The Interior Ponderosa Pine Type forms a narrow belt along the east side of the Sierra Nevada-Cascade Ranges, southern British Columbia, eastern Oregon and Washington, central and northern Idaho, western Montana, South Dakota, Utah, western Colorado, Arizona, New Mexico, and central Mexico. The Pacific Ponderosa Pine Type occurs on the lowermost west slopes of the Sierra Nevada and southern Cascade ranges and cross ranges of northern California and southern Oregon (Fowells 1965).

In other forest-habitat types (climax associations of species that show the strongest evidence of self-perpetuation on a site)--namely, Ponderosa Pine-Larch-Douglas Fir, Ponderosa Pine-Grand Fir-Douglas Fir, Ponderosa Pine-Sugar Pine-Fir, and Pacific Ponderosa Pine-Douglas Fir, ponderosa pine is a component of the climax cover, but never predominates unless the community is disturbed. The first habitat type is typical of western Montana, northern Idaho, northeastern Washington, and southern British Columbia. The Ponderosa Pine-Grand Fir-Douglas Fir Type, mixed-conifer, occurs primarily in eastern Oregon and central Idaho. The Ponderosa Pine-Sugar Pine-Fir Type is often called the Sierra-Nevada mixed-conifer in California where it is most extensive on the west slope of the Sierra Nevada Mountains (Fowells 1965). The Pacific Ponderosa Pine-Douglas Fir Type is typically found on the east slope of the north coast ranges of California and Oregon, the Siskiyou Mountains and southern Cascades.

Climate

Annual precipitation of climax ponderosa pine plant communities averages 20 inches (51 cm), but generally varies from 10 to 11 inches (25 to 28 cm) to 28 inches (71 cm) throughout western North America (Weaver 1951b, Brayshaw 1955, 1965, Fowells 1965, Foiles and Curtis 1973, Boldt and Van Deusen 1974, Currie 1975, Clary 1975, Skovlin et al. 1976). This variation is related to latitude, slope, aspect, soil type, and precipitation-to-evaporation ratio. In northern California, where ponderosa pine may be a seral or climax species, precipitation generally varies from 30 to 50 inches (76 to 127 cm) per year, but can be as high as 95 inches (241 cm) per year (P. M. McDonald, Research Forester, Redding, California, Pers. Comm.). Seral ponderosa pine

communities in eastern Oregon and Washington, Idaho, and western Montana grow where precipitation varies from 15 to 30 inches (38 to 76 cm) per year (Hall 1976).

Elevation

Elevation varies according to the geographical region. In British Columbia elevation for ponderosa pine ranges from 1,000 to 4,300 ft (305 to 1,311 m) (Brayshaw 1965). Along the eastern Flank of the Cascades and the Blue Mountains ponderosa pine grows at elevations from 1,600 to 5,000 ft (488 to 1,524 m) (Weaver 1951b, Harris 1954, Biswell et al. 1955, Franklin and Dyrness 1973, Skovlin et al. 1976). In California, it is most commonly found at elevations from 500 to 3,500 ft (152 to 1,067 m) in the north and from 5,300 to 7,300 ft (1,616 to 2,226 m) in the south (Fowells 1965). Ponderosa pine in the central and southern Rocky Mountains varies in elevation from 5,000 to 9,500 ft (1,524 to 2,896 m) (Currie 1975, Clary 1975), but is generally most common at elevations from 6,500 to 8,500 ft (1,982 to 2,591 m) (Cooper 1960, Schubert 1974, Clary 1975). In the Black Hills elevation for ponderosa pine ranges from 3,200 to 7,200 ft (976 to 2,195 m) (Gartner and Thompson 1972, Boldt and Van Deusen 1974). Although exceptions can be found, the best developed stands are at elevations of 4,000 to 8,000 ft (1,220 to 2,439 m) on benches, plateaus, and west and south aspects (Fowells 1965).

Soils

Soils may be derived from a variety of igneous and sedimentary rocks (Schubert 1974). Generally, however, soils of the ponderosa pine type have developed primarily from quartzite, argillite, schist, basalt, andesite, granite, or shale and, to a lesser extent, from limestone and sandstone (Foiles and Curtis 1973, Schubert 1974, Currie 1975). Soil textures generally vary from sands to clay loam and occasionally to clays (Arnold 1950, Ogilvie 1955). Trees grow best on loam soils and on moderately sandy or gravelly soils (Schubert 1974). Clay soils often inhibit germination of pine seeds and do not favor good tree development (Schubert 1974) because they yield less of their total water for plant growth and are better suited to the more drouth-tolerant plants such as grasses (Clary 1975, Skovlin et al. 1976).

NATURAL SUCCESSION WITH FIRE

Natural succession with fire in the ponderosa pine forest can be envisioned by the following sequence of events: windfall, insect attacks, mortality and then fire. Because of these events openings are created naturally (Cooper 1961, Weaver 1943, 1959, 1964). Ponderosa pine seed is blown on to the bare mineral soil of these openings from adjacent areas. Seedlings of ponderosa pine become established most easily on a bare mineral soil surface (Schultz and Biswell 1959) in open sunlight (Schubert 1974). Shade from larger trees, charred remains, stumps and fallen logs help to provide the necessary environment for seedling survival (Biswell et al. 1973). Later, grasses compete with the pine seedlings and partially thin them (Pearson 1942, Pieper and Biswell 1961). In grassy areas it will take healthy pine trees about 5 years to overcome competition from grasses, during which time they are susceptible to fire. It usually takes 8 years before the pine needles alone beneath young trees will be adequate to carry a fire (Cooper 1960).

While the openings are still predominantly grass, a subsequent fire will act as a natural thinning agent. The fire will be of a lower intensity than in the thick mats of pine needles, killing the smaller, thin-barked saplings and leaving the healthy, more vigorous trees (Biswell et al. 1973). Dense thickets of young ponderosa pine trees will not escape fire, causing the cycle to begin from mineral soil again (Morris and Mowat 1958, Hall 1976).

This type of regeneration in ponderosa pine forest resulted in a pristine forest that was represented by many age classes arranged in distinct groups, rather than in admixtures of all ages as found in climax forests (Biswell et al. 1973). Thus a pattern of disjunct groups or clusters of even-aged and even-sized trees, saplings, or seedlings existed, often less than 1 acre (0.4 ha) in size. Each class was separate; a healthy stand seldom contained older trees with younger reproduction growing under them (Biswell et al. 1973).

As passing surface fires helped to kill the younger, weaker trees, and dense thickets in a young pine stand, competition and stand stagnation were minimized. Nutrients in the litter were recycled (Vlamis et al. 1956, Moir 1966, Wollum and Schubert 1975). Lower branches and foliage of the remaining saplings and trees were pruned and thinned (Biswell et al. 1973), although pruning of the lower branches apparently does not stimulate leader growth (Barrett 1968) for height is controlled genetically (Wollum and Schubert 1975).

Repeated fires checked encroachment of the less fire-resistant species associates and pine seedlings in both seral and climax stands of ponderosa pine. This burning permitted the development of mature ponderosa pine trees with expanded canopies, sometimes nearly closed, thereby reducing herbaceous growth and increasing the thickness of

pine litter on the forest floor. As the trees reached greater heights in isolated groups, they became more vulnerable to lightning. The largest and often the oldest, trees were most commonly, and even repeatedly, struck by lightning (Biswell et al. 1973). These trees served as conductors which could ignite surface fires and burn dead and diseased trees, thickets, and heavy accumulations of fuels. Each time the fire produced an opening that included charred remains of former trees. Grasses and shrubs invaded along with the pine seedlings. Then the cycle repeated itself with a mosaic of even-aged groups of pines being maintained. This is a simplified picture of what happens in the "typical ponderosa pine forest type." A typical forest rarely exists, but all of these successional phases can be found in forests as well as variations of these successional phases.

VEGETATION AND FIRE EFFECTS

Since ponderosa pine is an integral component of six forest-habitat types in the West, each with different understory species, different associates, and somewhat different fire relationships, each type will be discussed separately in the sections to follow. Yields of the understory, however, will be discussed as a unit in the first section.

Understory Yield for Ponderosa Pine

Forage, particularly grasses and shrubs, are important components of seral and climax ponderosa pine communities. In the Black Hills, where ponderosa pine is a climax species, Pase (1958) found that understory compositions were approximately as follows: grasses and grass-like plants, 66 percent; forbs, 15 percent; and shrubs, 19 percent. Herbaceous yields generally range from 750 to 1,700 lb/acre (843 to 1,910 kg/ha) in openings of pine forests to less than 50 lb/acre (56 kg/ha) under 70 to 100 percent canopies (Pase 1958, Cooper 1960, Biswell 1972, Hall 1976, Severson and Boldt 1977). In the central and southern Rocky Mountains and the Black Hills of South Dakota, open ponderosa pine pole stands produced yields of 250 to 400 lb/acre (281 to 449 kg/ha) if thinned to a 45- to 60-ft basal area/acre (4.2 to 5.6 m^2/ha) (Smith 1967, Clary 1976, Severson and Boldt 1977). In eastern Washington, seral ponderosa pine communities in the Ponderosa Pine-Grand Fir-Douglas Fir habitat type produce 500 to 600 lb/acre (562 to 674 kg/ha) (Hall 1976). Shading and litter are the primary factors that depress plant yields beneath ponderosa pine trees. Pase (1958) and Biswell (1972) showed exponential relationships between litter and herbage production. Herbage yields decline rapidly as pine needles build up to 6,000 lb/acre (6,741 kg/ha). Thereafter, yields drop to 50 lb/acre (56 kg/ha).

The second year after burning in northern Arizona, forage yields increased from 72 to 613 lb/acre (81 to 689 kg/ha) on unthinned stands and from 490 to 638 lb/acre (550 to 716 kg/ha) on thinned stands (Pearson et al. 1972). The increases were due primarily to forbs. Grasses held steady or decreased slightly. First year yields had increased on thinned stands, but decreased slightly on unthinned stands.

CLIMAX PONDEROSA PINE COMMUNITIES

A. Regional Areas of the Interior Ponderosa Pine Type
East Slope of Cascades, Blue Mountains, Northern Rockies

Vegetation

This region includes parts of central and eastern Oregon and Washington, Idaho, western Montana and southern British Columbia. The understory of the ponderosa pine communities are dominated by grasses or shrubs (Brayshaw 1965, Daubenmire 1969). Common grasses include bluebunch wheatgrass (Agropyron spicatum), needle-and-thread (Stipa comata), Idaho fescue (Festuca idahoensis), and rough fescue (Festuca scabrella). Idaho fescue usually dominates the wettest sites, and bluebunch wheatgrass dominates many of the drier sites in Washington, Oregon and Idaho. Needle-and-thread is usually associated with sandy soils, but also is found in the driest areas. Rough fescue is most abundant east of the summit of the northern Rockies. It frequently grown in combination with Idaho fescue, but is more tolerant of cold weather. Other grass species present usually include Sandberg's bluegrass (Poa secunda), bottlebrush squirreltail (Sitanion hystrix), junegrass (Koeleria cristata), onespike danthonia (Danthonia unispicata), pinegrass (Calamagrostis rubescens), elk sedge (Carex geyeri), and letterman needlegrass (Stipa lettermanii). Heavily grazed areas are often dominated by cheatgrass (Bromus tectorum) (Weaver 1967a).

Mixed with the grasses are small amounts of numerous forbs including balsamroot (Balsamorhiza sagittata), woodland star (Lithophragma inflatum), Collinsia (Collinsia parviflora), whitlow grass (Draba verna), springbeauty (Montia linearis), forgetmenot (Myosotis micrantha), low pussytoes (Antennaria dimorpha), and silky lupine (Lupinus sericeus) (Daubenmire and Daubenmire 1968). Other vegetation includes wild strawberry (Fragaria sp.), bedstraw (Galium aparine), bigleaf sandwort (renaria macrophylla), fleabane (Erigeron compositus), and heartleaf arnica (Arnica cordifolia) (Brayshaw 1955, Hall 1973, Skovlin et al. 1976, Volland 1976). Fireweed (Epilobium angustifolium) is common on hotspots (Weaver 1951b). Overgrazed areas contain dalmation toadflax (Linnaria dalmatica) and common St. Johnswort (Hypericum perforatum) (Daubenmir and Daubenmire 1968).

Dominant shrubs are typically snowberry (Symphoricarpos albus), ninebark (Physocarpus malvaceus), oceanspray (Holodiscus discolor), smoothleaf sumac (Rhus glabra), and antelope bitterbrush (Purshia tridentata). Less abundant shrubs include shiny-leaf ceanothus (Ceanothus velutinus), birchleaf spiraea (Spiraea betulifolia), redstem ceanothus (Ceanothus sanguineus), willow (Salix sp.), rose (Rosa sp.), mockorange (Philadelphus lewisii), bittercherry (Prunus emarginata), and serviceberry (Amelanchier alnifolia).

Fire Effects

In general, fire is beneficial to grasses in ponderosa pine associations of eastern Oregon and Washington because it removes pine needle mats (Weaver 1951b). Because of the precipitation zone and the size of most plants, the bunchgrasses would recover from fire in 1 to 3 years, whereas most forbs would be harmed for no more than a year (Wright et al. 1978). All of the shrubs, except for antelope bitterbrush, are vigorous sprouters and very tolerant of fire. For most of these communities, Weaver (1967a) estimated a fire frequency of 6 to 22 years, and Arno (1976) documented an average fire frequency of 6 to 11 years with a range of 2 to 20 years.

By contrast, fire frequency in the ponderosa pine-bitterbrush habitat type (a widely distributed community in west-central North America) was probably burned every 50 years or so. This hypothesis is based on observations and current knowledge of the susceptability of antelope bitterbrush to fire (Nord 1965, Weaver 1967a, Wright et al. 1978). Following one fire in such a community, Weaver (1967a) noted that the ground was still comparatively free of fuel accumulations and brush after 20 years. After 27 years bitterbrush seedlings became frequent. In general, ponderosa pine communities with shrub understories apparently had lower fire frequencies than communities with grass understories (Arno 1976).

Central Rockies

Vegetation

Currie (1975) has described vegetation of ponderosa pine-bunchgrass ranges of the central Rockies. Generally six forage species--Arizona fescue (Festuca arizonica), mountain muhly (Muhlenbergia montana), bluegrama (Bouteloua gracilis), sun sedge (Carex heliophila), little bluestem (Schizachyrium scoparius), and fringed sagebrush (Artemisia frigida)--make up 95 percent of the herbage composition by weight. Arizona fescue and mountain muhly dominate the southern two-thirds of the zone. Northward at the northern border of Colorado and into Wyoming, Idaho fescue replaces Arizona fescue. At the upper limit of the ponderosa pine zone, Thurber fescue (Festuca thurberi) will replace Arizona fescue and may be associated with Idaho fescue. Other desirable grasses include parry oatgrass (Danthonia parryi), junegrass, little bluestem, blue grama, western wheatgrass (Agropyron smithii), slender wheatgrass (A. trachycaulum), and bottlebrush squirreltail. Less desirable grasses include sleepygrass (Stiparobusta), pullup muhly (Muhlenbergia filiformis), and tumblegrass (Schedonnardus paniculatus). The most conspicuous forbs are geraniums (Geranium sp.), purple milkvetch (Astragalus striatus), western yarrow (Achillea lanulosa), Lambert loco weed (Oxytropis lambertii), pussytoes (Antennaria rosea), trailing fleabane (Erigeran flagellaris), cinquefoils

(Potentilla sp.), asters (Aster sp.), and bluebells (Mertensia sp.). Shrubs are not very prevalent, but in local areas bearberry (Arctostaphylos uva-ursi), true mountain mahogany (Cercocarpus montanus), Gambel's oak (Quercus gambelii), and ceanothus (Ceanothus sp.) are present.

Fire Effects

Daubenmire (1943) indicates that fire probably had a significant role in ponderosa pine forests of this region. Based on the predominantly grass understory, this assumption could easily be true. Certainly the grasses could tolerate fire well. However, since litter is usually meager and the tree canopy is generally no more than 25% (Daubenmire 1943), one could also reason that fire is less frequent in ponderosa pine communities of this region than in most other areas where it grows. There seems to be less fine fuel for potential fires, and fire frequency may be closer to the estimated 12- to 25-year interval as suggested by Hendrickson (1972).

Southern Rockies

Vegetation

Ponderosa pine is generally the climax tree where it occurs in pure stands in this region. However, litter builds up quickly and this area has a high incidence of lightning strikes (Komarek 1966). Principal grass species in the pine understory include mountain muhly, muttongrass (Poa fendleriana), Arizona fescue, black dropseed (Sporobolus interruptus), pine dropseed (Blepharoneuron tricholepis), bottlebrush squirreltail, sedge (Carex geophila), and blue grama (Arnold 1950), although mountain muhly and Arizona fescue are the dominant grasses (Clary 1975). Most abundant forbs include western yarrow, pussytoes, sandwort (Arenaria fendleri), senecio (Senecio sp.), fleabane, thistle (Cirsium sp.), asters, penstemons (Penstemon sp.), clovers (Trifolium sp.), and lupine (Lupinus sp.).

Fire Effects

Grazing and presumably burning are most harmful to mountain muhly, Arizona fescue, muttongrass, and pine dropseed (Arnold 1950). Mountain muhly takes at least 3 years to fully recover from fire (Gaines et al. 1958); it dropped from 70 to 60% of the total grass density 2 years after burning. Bottlebrush squirreltail, a seral species, will increase five-fold by the end of the second year after burning (Gaines et al. 1958). Forbs are generally harmed very little because their foliage has disintegrated by the time of the burn. Fendler ceanothus (Ceanothus fendleri) is the only browse species over most of this area (Kruse 1972), which produces numerous seedlings after fire (Pearson et al. 1972). Alligator juniper (Juniperus deppeana) and Gambel's oak, both sprouting

species, invade stands of ponderosa pine at the lower elevations, but fire along with competition and shade from pines will keep these species in check (Leopold 1924).

Black Hills

General Comments

Comparison of photographs taken in 1874 and retaken a century later from the same camera points in the Black Hills clearly illustrates how forests can change under prolonged fire protection and intensive land use (Shideler 1972, Progulske 1974). Many pine stands are much denser than they were before human settlement, and the aggressive pine has occupied many of the smaller grassy openings. Ponderosa pine reproduces more prolifically in the Black Hills, year in and year out, than almost anywhere else in the species' vast range (C. E. Boldt, Silviculturist, Rapid City, North Dakota, Pers. Comm.). Fire today is being tested as a tool to check encroachment of pine into grasslands (Gartner and Thompson 1972).

Vegetation

Vegetation of commercial timber land in the Black Hills area has been described by Pase (1958). Ponderosa pine occupies 95% of the area. White spruce (Picea glauca), an extension of the Boreal Forest, accounts for the remaining 5% on moist northerly slopes at higher elevations. Paper birch (Betula papyrifera) and aspen (Populus tremuloides) occupy cool, moist sites throughout the northern half of the Black Hills, often forming dense stands on old burns. Bur oak (Quercus macrocarpa) can be found on the northern fringe of the Black Hills. Other species mentioned by Gartner and Thompson (1972) include willows, redosier dogwood (Cornus stolonifera), water birch (Betula occidentalis), elm (Ulmus americana), boxelders (Acer sp.), cottonwoods (Populus sp.), and mountain ash (Sorbus scopulina). True mountain mahogany is the most extensive shrub community found in the Black Hills. Other understory shrubs include common juniper (Juniperus communis), bearberry, russet buffaloberry (Sheperdia canadensis), red raspberry (Rubus strigosus), chokecherry (Prunus virginiana), wild plum (P. americana), pin cherry (P. pennsylvanica), western snowberry (Symphoricarpos occidentalis), eastern hop-hornbean (Ostrya virginiana), hazelnut (Corylus rostrata), serviceberry, rose, and Oregon grape (Mahonia repens) (Thilenius 1971).

Principal understory herbaceous species include Pennsylvania sedge (Carex pennsylvanica), Kentucky bluegrass (Poa pratensis), roughleaf ricegrass (Oryzopsis asperifolia), poverty oatgrass (Danthonia spicata), fuzzyspike wildrye (Elymus innovatus), prairie dropseed (Sporobolus heterolepis), little bluestem, western yarrow, Missouri goldenrod (Solidago missouriensis), American strawberry (Fragaria vesca), pussytoes, white clover (Trifolium repens), and cream peavine (Lathyrus ochroleucus).

Under dense canopies, Pennsylvania sedge, Missouri goldenrod, peavine, common juniper and Oregon grape were the most persistent plants. Poverty oatgrass, bearberry, western snowberry, and serviceberry were moderately tolerant of shade. A tree canopy cover of 40% is the breaking point where many species begin to disappear (Pase 1958).

Fire Effects

The response of understory species in this plant association to fire has not been studied. Based on other studies, however, most of these species are tolerant to fire. Gartner and Thompson (1972) have studied the effect of fire on plants in grasslands adjacent to the Black Hills. Their data show that sedges, prairie dropseed, Missouri goldenrod, cream peavine, and chokecherry tolerate fire very well. Erdman (1970) found that true mountain mahogany was a vigorous sprouter in southern Colorado.

Season of the fire would have the greatest effect on herbaceous plants. According to Orr (1959), severe thunderstorms are common during summer months. During this time of the year fires could spread in heavy grass (mixture of dead and green grass) or needle litter and severely harm warm season species and favor cool season species such as Kentucky bluegrass, an introduced species. Spring burning, on the other hand, would favor warm season grasses and harm cool season species.

B. Pacific Ponderosa Pine Type

General Comments

The Pacific Ponderosa Pine Type occupies the lower-most slopes of the Sierra Nevada Mountains and southern Cascade range and cross ranges of northern California and southern Oregon (Fowells 1965). It is found mostly on sites of high quality where it tends to form dense stands (P. M. McDonald, Research Forester, Redding, California, Pers. Comm.). It is a climax type, although the area it occupies shifts with disturbance. At low elevation, ponderosa pine can be found on outliers of higher site quality where it outgrows the manzanitas (Manzanita sp.) and oaks (Quercus sp.). Lack of disturbance aids species extension; disturbance causes its retreat. At the upper elevational limits of the type, the more tolerant conifers invade and, without disturbance, capture the area. Disturbance favors extension of the Pacific Ponderosa Pine Type into the Sierra Nevada mixed-conifer zone. Stand structure reflects the magnitude and timing of disturbance; hence vegetation pattern tends toward even-aged groups in an uneven-aged mosaic.

Vegetation

Shrub and herbaceous vegetation in the Pacific Ponderosa Pine Type is varied and abundant. However, it is sparse beneath dense stands, but increasingly abundant as stand density decreases. Because of the high site, disturbed areas do not remain bare for long. Resprouts of many shrub species as well as dormant shrub seeds in the soil burst forth to pioneer succession. Numerous invader species (annual grasses and forbs) also are blown by wind. Together the pioneer and invader species constitute a formidable challenge to conifer regeneration. Manzanita, deerbrush (Ceanothus integerrimus), coffeeberry (Rhamnus californica), a variety of oaks, poison oak (Rhus diversiloba), snowberry and other ceanothus species, plus a host of annual forbs and grasses, constitute the understory at lower elevations in this forest type.

Fire Effects

Except for some of the manzanita species, all of the shrubs are vigorous sprouters following fire and some reproduce from seed. Annual plant seeds are also abundant, so these species come back quickly after fire. The abundance of shrubs and grasses after a prescribed burn is often difficult to deal with following prescribed burns. They are very competitive with pine seedlings. However, slash reduction is inescapable, and if done properly, prescribed burning shows positive potential (McDonald and Schimke 1966).

Prescribed burning trials in stands of the Pacific Ponderosa Pine Type were conducted along roadsides in the winter (P. M. McDonald, Research Forester, Redding, California, Pers. Comm.). These were limited trials involving only 1 or 2 acres (0.4 to 0.8 ha) of land. Nevertheless, conifer and hardwood seedlings and saplings under 100-year-old ponderosa pines were reduced greatly, extending the scenic view and reducing the hazard of roadside fires.

SERAL PONDEROSA PINE COMMUNITIES

A. Ponderosa Pine-Larch-Douglas Fir Type

Vegetation

This habitat type occurs primarily in western Montana, northern Idaho, northeastern Washington and southern British Columbia. It occupies areas that are intermediate between the dry ponderosa pine lands and the more moist Larch-Douglas Fir Type. It is presumed to be a subclimax type successionally, often having a definite fire origin and tending to pass slowly into a Douglas fir climax with significant amounts of ponderosa pine and western larch (Larix occidentalis). Other species occurring in limited amounts are grand fir (Abies grandis) and lodgepole pine (Pinus contorta).

Common grass and forb associates include rough fescue, pinegrass, elk sedge, Idaho fescue, bluebunch wheatgrass, balsamroot, and heartleaf arnica. The more common shrubs associated with ponderosa pine in this cover type are blue huckleberry (Vaccinium globulare), dwarf huckleberry (V. caespitosum), ninebark, bearberry, chokecherry (Prunus virginiana, P. pennsylvanica, P. virginiana var. melanocarpa), serviceberry, woods rose (Rosa woodsii), bitterbrush, oceanspray, redstem ceanothus, snowberry, birchleaf spiraea, mock-orange, and shiny-leaf ceanothus.

Fire Effects

Because ponderosa pine is more fire resistant than most associated tree species (except western larch), past fires have had a profound effect on its distribution. Although young seedlings are readily killed by fire, older trees are protected from fire damage by their thick bark. Associated species such as Douglas fir and grand fir are considerably less fire tolerant, especially in the sapling and pole-size classes. As a result, periodic fires have maintained ponderosa pine in this cover type where, without fire disturbance, climax species would have attained dominance.

Fire has also influenced understory vegetation. Several workers have observed that burning reduces shrub cover substantially and increases grass cover, especially on the more xeric sites (Brayshaw 1965, Daubenmire and Daubenmire 1968). In seral ponderosa pine stands maintained by fire, pinegrass, a very fire-tolerant species, dominates the herbaceous layer along with other grasses on some sites (Brayshaw 1965, Hall 1976). As litter accumulates and crown cover closes (as results from long fire-free intervals), heartleaf arnica becomes dominant (Brayshaw 1965).

Of the shrubs associated with this cover type, antelope bitter-brush is the most readily eliminated by fire, although on some sites

fire exclusion and consequent competition from increases in canopy density may have the same effect (Sherman 1966). Rodent caches of seed, however, are also significant in the establishment of antelope bitterbrush, and cache placement pattern is strongly correlated with sites free of pine litter (Sherman 1966). As a result of fire exclusion, litter-free sites are becoming less abundant and a decrease in bitterbrush populations may be anticipated.

The majority of shrubs associated with ponderosa pine in this cover type are well adapted to fire and resprout vigorously. In western Montana Miller (1977) documented the sprouting ability of blue huckleberry, mountain huckleberry (V. membranaceum), snowberry, and birchleaf spiraea. Redstem ceanothus will resprout, but it also comes back as a vigorous seedling following fire (Orme and Leege 1976). Heat causes the hilar fissure to permanently open and allow water to enter the seed. Shiny-leaf ceanothus also resprouts and germinates from seed following fire (Lyon and Stickney 1976). Other species that easily regenerate from root crowns include willow (Salix scouleriana), mountain maple (Acer glabrum), and serviceberry (Lyon and Stickney 1976). Additional research has been summarized by Wright (1971) which shows that chokecherry, ninebark, oceanspray, woods rose, and snowberry are also vigorous sprouters. The grasses and forbs best adapted to fire are pinegrass, arnica (Arnica latifolia), and braken fern (Pteridium aquilinium) (Lyon and Stickney 1976).

B. Ponderosa Pine-Grand Fir-Douglas Fir Type

Vegetation and Fire Effects

Plant communities of ponderosa pine in eastern Washington, eastern Oregon, and central Idaho are usually seral to climax mixtures of the Ponderosa Pine-Grand Fir-Douglas Fir habitat type (Hall 1976). This type is also referred to as mixed-conifer. Forests of this habitat type vary in their composition, but the primary type of concern here contains ponderosa pine, Douglas fir, grand fir, and sometimes western larch.

For the seral communities of ponderosa pine which have been maintained by fire, pinegrass, a very fire tolerant species, dominates the herbaceous layer with elk sedge as a co-dominant (Hall 1976). As litter accumulates and the crown cover closes, heartleaf arnica becomes dominant (Hall 1976). Shrubs are rare in seral communities of mixed-conifer, but usually very abundant in seral communities of ponderosa pine-Douglas fir. The most common shrubs are snowberry, ninebark, oceanspray, and birchleaf spiraea--all vigorous sprouters following fire (Weaver 1967a).

Ponderosa pine is the most fire-tolerant species of all trees in the mixed-conifer zone because it has a fire resistant bark containing

a 1/8- to 1/4-inch (0.3- to 0.6-cm) thick dead layer at 2 inches (5 cm) diameter (Hall 1976). Grand fir bark, on the other hand, remains green and photosynthetically active up to 4 inches (10 cm) in diameter (Hall 1976). Thus, it is easily killed by surface fires; it can even be killed by sunscald (Hall 1976). Douglas fir is intermediate in susceptability to fire.

C. Ponderosa Pine-Sugar Pine-Fir Type

Vegetation

In the Sierra Nevada mixed-conifer forest type, ponderosa pine is part of a complex six-species mixture, which as a whole is considered climax. Early travelers recorded that these forests were dominated by ponderosa pine with some incense cedar and California black oak (Quercus kelloggii) at the lower elevations, and increasing numbers of sugar pine (Pinus lambertiana) and white fir at the upper end of the zone (Van Wagtendonk 1974). Douglas fir was more prevalent in the northern portion of the region. Today, ponderosa pine occurs both as individual trees or in small stands or groves. Occasionally, it is found occupying an entire hillside, especially on south or west aspects. Site quality generally is high, and as might be expected, the stands tend to be dense on the south and west aspects. The different tree species in the Sierra Nevada mixed-conifer vary in shade tolerance; thus all strata in the stands have become occupied because of protection from fire.

Lesser species commonly consists of less than 10 species beneath dense stands, but in the type as a whole over 100 species of grasses, forbs, and shrubs have been identified (P. M. McDonald, Research Forester, Redding, California, Pers. Comm.). The understory, where present, includes young tree reproduction, Mariposa manzanita (Arctostaphylos manzanita), wedgeleaf ceanothus (Ceanothus cuneatus), deerbrush, and gooseberry (Ribes sp.). The first two are non-sprouters and depend on seed for survival. Beneath the larger trees the forest floor is carpeted with needles, bear clover (Chamaebatia foliolosa) and various grasses and forbs (Van Wagtendonk 1974).

Fire Effects

The less shade-tolerant ponderosa and sugar pines are best adapted to a regime of periodic surface fires and would be favored with prescribed burning (Van Wagtendonk 1974). However, protection from natural surface fires has permitted the forest floor to become a tangle of understory vegetation and accumulated debris. Shade-tolerant incense cedar and white fir thickets often predominate in the understory. Thus, a wildfire in this forest, as it exists today, could easily reach catastrophic proportions. For those who wish to reintroduce fire into the Sierra Nevada mixed-conifer forest, it will have to be done carefully with refined prescriptions (Van Wagtendonk 1974).

D. Ponderosa Pine-Douglas Fir Type

Vegetation

This type is widely developed in northern California and southern Oregon, particularly in the north coast ranges and Siskiyou Mountains. Ponderosa pine and Douglas fir together predominate, although neither species is present to the extent of 80%. Incense cedar, sugar pine, and a variety of other conifers and oaks are often present in small amounts.

Many annual grasses and forbs, including legumes, as well as perennial plants such as mountain brome (Bromus carinatus) and blue wildrye (Elymus glaucus) are common in this area. Major forb genera include Madia, Lotus, Epilobium, Cirsium, Clarkia, and Trifolium. Common annual grass genera are Bromus, Festuca, and Hordeum.

Common and white-leaf manzanita (Arctostaphylas manzanita and A. viscida), both non-sprouting shrubs, and deerbrush, a sprouting species, are the most prevalent shrubs (Biswell and Schultz 1958, McDonald 1976a). Occasional stands of western mahogany (Cercocarpus betuloides), mountain whitethorn (Ceanothus condulatus), hazel (Corylus rostrata var. californica), and flowering dogwood (Cornus sp.)--all sprouting species--are also present. Greenleaf manzanita (A. patula), shiny-leaf ceanothus, sierra plum (Prunus subcordata), and bush chinkapin (Castanapsis sempervirens) also occur in ponderosa pine communities of northern California (Bentley et al. 1971). Prevalent tree species include Pacific madrone (Arbutus menziesii) and various oaks (Quercus sp.).

Fire Effects

After-logging, slash volumes ranged from 88 to 110 tons/acre (217 to 272 metric tons/ha) in this forest type (Sundahl 1966). The need for slash reduction is inescapable. If site preparation also can be accomplished simultaneously, costs to restock a forest can be reduced. Controlled burning of 14 different compartments totaling 331 acres (372 ha) over 4 years indicated the positive potential of this technique (P. M. McDonald, Research Forester, Redding, California, Pers. Comm.). Specific planning, prescriptions, and care, however, must be used (McDonald and Schimke 1966). Drawbacks are dependent on rather specific weather and the propensity for breaking dormancy of copious brush seeds in the soil.

Shrubs can be very prevalent after a burn because of their ability to sprout. However, other than general observations, no specfic fire effects data is available for the shrub and herbaceous species.

MANAGEMENT IMPLICATIONS

How should a ponderosa pine forest be managed? A widely applied management scheme is a two-stage shelterwood cutting method (Schubert 1974, Boldt and Van Deusen 1974, McDonald 1976b). This regeneration method seems to work well in climax communities of ponderosa pine and in some successional pine stands where the associated conifers are desired species. However, in successional pine stands of the Pacific Northwest where ponderosa pine is preferred over Douglas fir and grand fir, the seed-tree method is used to allow more light through the canopy (Hall 1973).

Shelterwood cutting, in most cases, involves the removal of all merchantable trees except for 12 to 18/acre (30 to 44/ha) residual, large, full-crowned and thrifty trees that are left to produce seed and some shade. Advance reproduction, small poles, and large poles usually remain in the understory. On good sites, slash is disposed of both in individual piles and in windrows (McDonald 1976a, 1976b). In the Interior Ponderosa Pine Type, however, everything except the residual shelterwood trees is usually lopped and scattered (Boldt and Van Deusen 1974, Dieterich 1976). After 10 years or so, if the new stand is more than adequately stocked (80% or more of the milacres are occupied by at least one solidly established pine tree 0.3 to 0.9 m tall), stagnation may become a threat.

Thus, the shelterwood and seed-tree methods, as presently used, are highly satisfactory for regenerating ponderosa pine, but they may lead to over-stocked seedling stands. The reason is that they provide only a low level of control over seed dispersal and seedling establishment. Seed tree cutting (4 to 12 residual seed trees/acre (10 to 30/ha), of course, provides better control than the shelterwood cutting method, but control may be reduced by advanced reproduction or seed dispersal before harvest. Some additional control may be attained by limiting site disturbance and allowing grasses and shrubs to compete, but such vegetation must be present and competitive at time of the regeneration cut. Grazing should probably be restricted to protect seedlings when pine stocking is marginal, as well as to enhance competition by ground cover when pine production is too abundant.

For those who wish to use silviculture as a tool to obtain maximum production of wood products, natural regeneration is uncertain (Rietveld and Heidman 1976) and therefore clearcutting and planting is the preferred method to establish ponderosa pine trees (Shearer and Schmidt 1970). However, silviculture should be a means of improving the quality and diversity of the landscape and of providing as high a potential for a variety of uses as is compatible with carrying capacity of the land (Meyers 1974).

Once a new forest has been established, there should be an adequate number of trees 10 to 12 ft (3 to 3.7 m) tall before regular prescribed burning begins, although low intensity burns will leave trees 6 to 8 ft (1.8 to 2.4 m) tall unharmed (Biswell 1968). Here, the primary goal is to reduce the density within a range of 125 to 260 trees/acre (309 to 642 trees/ha) (Barrett 1968, 1973). Additional benefits will be to reduce surface fuels, and regenerate desirable shrubs where applicable. Subsequent fires at 5-to 7-year intervals can be used to maintain low fire hazard conditions and kill unnecessary reproduction so that a stand of healthy trees will develop. Burns are conducted in the fall in most areas, although Biswell (1968) recommends winter and spring burning for California.

McComb (Wildlife Biologist, Colville, Washington, Pers. Comm.) has been using a modification of the traditional shelterwood cutting method. By leaving the slash in place, packing it with a dozer, and then burning it, he has obtained good regeneration of ponderosa pine as well as shiny-leaf ceanothus and redstem ceanothus. Moreover, with this method of prescribed burning, fuel loads are reduced, and low fire intensities can be used in future years for thinning and maintenance of low fire hazards. Seed production from ponderosa pine trees remains adequate as long as percent of crown scorched remains less than 65% (Rietveld 1976). Trees scorched less than 35% are the best seed producers (Reitveld 1976).

In other cases, selective cutting or thinning may be the first treatment in a ponderosa pine forest. These forests are not ready for the two-stage shelterwood or seed-tree cutting methods. Biswell (1968) suggests that in such forests the heavy debris be removed by a series of prescribed fires. Fire can be used to maintain low fire hazard conditions and kill tree reproduction until the forest is ready to be harvested by clearcutting, a two-stage shelterwood method, group selection, or the seed-tree method and then burned.

Dense stands of pine saplings or mature stands of ponderosa pine with dense understories of young trees pose one of the most serious management problems. Few saw-log trees will be produced without major mechanical and hand thinning (Barrett 1973), which is expensive (Weaver 1943). Prescribed fire shows potential for thinning uneven-aged stands of trees if one is willing to accept the risk of some commercial timber losses (Weaver 1961, Lindenmuth 1962), but not for thinning dense, even-aged stands (Gordon 1967). There is no easy solution. Looking at the picture on a long-term basis, these forests should be reclaimed as soon as possible because the trees are capable of growing several times faster (Weaver 1959), Barrett 1973, Hall 1976). Destroying the stand and starting anew is one alternative (Boldt and Van Deusen 1974), but only if the area is not seeded immediately to grass. Where grass must be seeded after burning to prevent soil erosion, hand or mechanical thinning may be the only alternative. Hand

or mechanical thinning can save 10 years of stand growth (Barrett 1973), but such thinning seriously increases the fire hazard for 5 years (Fahnestock 1968).

Seeding or planting trees after a dense cover of grass is established usually results in total failure. This method is not the way nature tried to establish trees. Grasses were thin on many areas after a burn and thickened gradually. Where possible, competition must be kept to a minimum during the first year or two after the establishment, and thus the seeding of grasses on timber sites should be kept to a minimum (Rietveld and Heidmann 1976).

We have stressed the management of trees in this section because it is the primary resource on timber sites. However, the other resources--forage, wildlife, water, and recreation--will be present and esthetically pleasing if the area is managed to optimize a resource or combination of resources, including wood (Meyers 1974, Severson and Boldt 1977).

In conclusion, fire should play a much greater role in the management of our ponderosa pine forest than it does today, although it is not equally necessary in all associations that support ponderosa pine. It will take much time to get ponderosa pine forests to the stage where they can be easily managed with fire. But once that stage is achieved, fire hazards and suppression costs will be reduced, investments for cultural treatments will decline, yet forests will be both more productive and attractive.

STATE OF THE ART AND RESEARCH NEEDS

We know how to maintain clean understories of saw-log ponderosa pine stands that primarily have a litter and grass understory, but we do not have the answers to burning heavy accumulations of debris and shrubs or using fires to thin dense stands of ponderosa pine safely and economically. Much hand work seems necessary.

It appears that we need more research to improve upon nature's random way of keeping ponderosa pine stands thinned and of keeping the fire hazard low. Many natural fires were probably too cool or too small to be effective in thinning ponderosa pine (by human standards) and many were far too hot. Burning a wide variety of ponderosa pine stands (all ages, densities, accumulations of debris, locations, habitat types, etc.) under a wide variety of weather conditions needs to be done over a 10- to 25-year period before we can put into practice the potential uses of prescribed fire that have been observed by Biswell, Weaver, and Kallander. At present the limits of weather conditions for prescribed burning in relation to the many objectives that we wish to achieve in a wide variety of ponderosa pine stands are not fully known. Fire prescriptions for a wide variety of purposes will have to be documented before we can expect to see prescribed burning adopted on a large scale for management. Biswell et al. (1973) documented some conditions under which burning can be done. But we know that nature burned under a much wider variety of conditions and maintained the forests in a very open park-like condition (Progulske 1974).

Fire effects data on herbage and shrubs by species, needs to be documented more carefully. Most studies about the effect of fire on ponderosa pine understories have only talked about grasses, forbs, and shrubs in generalities. More data on individual species is needed to answer questions like these. Do shifts in composition take place after burning? If so, how long does it take the most desirable species to fully recover?

Thinning ponderosa pine stands with fire seems to be an area of major controversy. The interaction between fire, seedling establishment, competion from grasses, and grazing by cattle and wildlife needs to be looked at carefully. This is an area of research that needs high priority along with a study of economic tradeoffs as was done for the southern Rockies (Clary et al. 1975). Then researchers need to document how dense stands can be thinned with fire, if it can be done at all. At this stage it does not appear likely that fire can be used to thin large areas of even-aged dog-hair thickets, but it can be used to kill the dog-hair stands and prepare the site for a new forest. Such areas may need to be burned twice before seeding or planting. To avoid such drastic treatments and keep regeneration costs low by

natural methods, it appears that ponderosa pine forests should contain a mosaic of grasses, forbs, shrubs and trees for regeneration, thinning, maximum saw-log production, and protection from sweeping crown fires. This would involve the use of fire in ponderosa pine forest at 5- to 10-year intervals.

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